DÆDALUS

JOURNAL OF THE AMERICAN
ACADEMY OF ARTS AND SCIENCES

Art and Science

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Leon Cooper
Alistair C. Crombie
Daniel C. Dennett
Samuel Y. Edgerton, Jr.
Howard Gardner
Susan P. Gill
Gerald Holton
Anthony Smith
Leo Steinberg
Victor F. Weisskopf

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Preface to the Issue, "Art and Science"

WHAT IS ART? WHAT IS SCIENCE? The questions, superficially simple, are in fact surprisingly complex. They are not susceptible to facile answers. Determining the relations between art and science, searching for their common denominators, at least in the modern world, establishing correspondences and congruities, becomes a formidable task. How art and science relate to technology, why they should be thought relevant to morality, and what their study can possibly contribute to the understanding of the nature of the mind—a question of capital importance in our day—are only a few of the subjects explored in the pages that follow.

This issue of *Daedalus,* while not lacking in "design," owes a great deal to accident. Inspired largely by a conference held at the House of the Academy in December 1985, *fortuna* figured prominently in determining how the volume came to have its present form. This needs to be acknowledged at the outset; otherwise its content becomes bewildering, even deceptive. The Table of Contents cannot be read as the work of a committee; authors have not responded to a plan created by others. The two-day conference failed to provide a draft agenda for the issue. How could it have been otherwise? Could so cosmic a subject, touching on such disparate themes, have been contained, defined, segmented, and parcelled out in "bite size" intellectual morsels to a group of waiting authors? Those who met at the Academy, given their interests, might not have agreed even about a title for the issue, let alone about its contents. While some would almost certainly have opted for a term like "arts and sciences," preferring the plural to the singular, the choice of the singular is neither haphazard nor can it be read simply as a respectful tribute to the introductory essay to the issue. Rather, it needs to be read as a blunt assertion that art and science are best understood as two vast and largely independent domains, at least in the twentieth century.

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Had we used the plural—"arts and sciences"—emphasis would have been given to the divergences within each of these vast domains. The arts, for example, in their contemporary guise, embrace activities and accomplishments of great variety. On a gross level, the distinction may be made between the performing arts and the plastic arts, between a domain dominated by dance, music, and drama, and one dominated by painting, sculpture, and architecture. On a finer scale, more discriminating differences are easily established. So, also, when we approach the sciences today, we must discriminate between major disciplines, between fields as distinct as chemistry, physics, astronomy, biology, and geology. To dwell on these differences, explaining their significance, methodologically and analytically, is to chart something of the intellectual scientific landscape of our time. Yet, even such broad categories no longer suffice to distinguish between what one research scientist does and what his colleagues do. Specialization, in our time, has created subfields, identifying scientists in ways that the older categories no longer do. It is not enough today to identify someone as a biologist or a chemist; some adjectival differentiation is needed to specify the kind of biology or chemistry being pursued.

Those who speak of the sciences collectively acknowledge some sort of intellectual kinship; implicitly, they recognize a community, however various are its constituent parts. Still, there are conventions that govern membership in that scientific league. Few natural scientists, for example, would eagerly accept social scientists as "scientific" colleagues. Research on the brain, essential for the development of cognitive science, may or may not qualify as science, depending on the criteria used. So, also, artificial intelligence—a "new science" for some, a dubious intellectual enterprise for others—does not immediately find its intellectual niche, at least with many whose scientific credentials are thought to be impeccable.

Any contemporary discussion of the arts and the sciences, as any discussion of art and science, must start with the understanding that the meanings that attach to these words today would have been virtually incomprehensible two hundred or more years ago. When, for example, the American Academy of Arts and Sciences was established in 1780, its title conveyed messages scarcely communicated today. In the eighteenth century, the arts were not thought to depend principally on the supposed originality, genius, or creativity

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of an individual artist; many of the arts were deemed useful, particularly in their application to agriculture or commerce. Many had an avowedly artisanal base, more significant perhaps than anything that could be mistakenly called aesthetic. The idea that art should be equated only with such accomplishments as painting, music, and *belles lettres* would have seemed an unnecessary narrowing of a larger and more distinctive intellectual category.

So, also, in its perception of science, or the sciences, the eighteenth century used an optic substantially different from any employed today. It was not so much that scientists knew less about the universe then than they know today, but that the whole system was dominated by an ethic, and enjoyed institutional and other supports significantly different from any that are now common. Also, science, as a cumulative endeavor, which took for granted that one generation would stand on the shoulders of its predecessors, started with a seventeenth-century "point of departure" that has since been very substantially obscured.

If there is much in this issue that contrasts the art and the science of the twentieth century, there is also a good deal to suggest that the biological and the physical sciences, in their contemporary research modes, may be growing apart, with biological science showing a probabilistic proclivity that distinguishes it from the more absolute prediction claimed by physical science. It is not an accident that the theme of prediction figures so prominently in this issue, that the predictive power of the physical sciences is recognized to be different from that of the biological sciences, and different again from anything at all common in the arts.

The history of the nineteenth and twentieth centuries might well be written as an extended commentary on how the terms "art" and "science" have changed their meanings, gaining new sorts of notoriety and influence, raising new expectations, at the same time generating large misgivings and fear. If the historian of art needs to be attentive to the anxiety and anger that art generates, so the historian of science would do well to reflect on the sentiments that science and technology spawn, even in areas that appear to be superficially benign. A sense that pervades this issue, particularly evident perhaps in the last essays, concerns the "information revolution" of our day—so much touted by the mass media—which may be creating a society fundamentally inhospitable to certain traditional values, uncongenial

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to many who have memories of other times and other things. This is more than just nostalgia for a world that is lost.

It may be that, in the twentieth century, art and science have become largely distinctive—two very different expressions of human creativity—and that, more recently, the reality of these "two cultures" has been generally accepted, a consensus sufficient to create a small intellectual "cottage industry," whose principal tenets are now well-known. The conventional wisdom is that, while the scientist may occasionally dabble in the arts, those who do not actively pursue science are unlikely to cross over into the other very specialized domain. A great segment of contemporary intellectual life is thereby permanently closed to a very substantial part of the population, even in supposedly "advanced" societies. While it would serve little purpose to judge the validity of these propositions, it must be acknowledged that they have had one indubitably good effect—they generated interest in improving scientific instruction for all. Given the alternative—the perpetuation of a generation of scientific illiterates—the incentives to reform school curricula have been overwhelming. *Daedalus* addressed this problem most recently in a special issue on "Scientific Literacy" (Spring 1983); in this volume, the emphasis is substantially different. Our major concern has been to discover whether there may indeed be significant congruities between art and science today, whether such correspondences ever existed, what they tell us about creativity in art and science, and whether new light can be shed on how the creative artist and scientist go about their work. While no specific effort has been made to define the so-called *Zeitgeist* of our time, since that "spirit" obviously conditions what the artist and the scientist do, what they deem important, it must figure in any analysis of the trends of contemporary culture.

Given the complexity and difficulty of the subject, it is not surprising that substantial differences exist among the authors. It would be a mistake, however, to imagine that the issue is concerned principally with pitting the artist against the scientist—no such vulgar purpose would have had any appeal to those who wrote for this issue. There is no encounter in these pages between art historians and physicists, classicists and psychologists, philosophers and biologists. These are not two warring camps with antithetical purposes, which is not to say that common purposes are stressed, or that the same

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agenda is said to exist for both. No one argues that scientists and artists see their work validated in the same way.

The correspondences that may once have existed between art and science, that were certainly evident during the Renaissance, that may have continued well into the eighteenth century, have been dissipated. This, however, must not be taken to mean that they cannot become preeminent again. Indeed, one of the more arresting observations of authors in this issue suggests that if really significant progress is to be made in our efforts to understand the nature of the mind—an item high on the agenda of many—there must be a major reconciliation between art and science. This theme relates closely to a number of others that raise unsettling questions about the nature of today's information technology, that seek to predict its possible future roles in a new kind of universal culture.

At one time we considered publishing great parts of the transcript of the December 1985 meeting. For many reasons, not the least important being the reservations of a number of participants, the decision was made to publish only small segments; they appear at the end of the volume, and are intended to supplement the essays.

A great debt is owed those who attended the meeting, who helped to suggest the kinds of materials that we needed. A special debt is owed Leo Steinberg. Because his comments at the *Daedalus* meeting were arresting, provoking lively discussion, we hoped to publish them. He would not consent to this, believing them to be too casual, too random. Instead, he has written an essay that goes considerably beyond what he said at the Academy, that reflects on what others argued, and helps illuminate issues that are absolutely central to our concerns. Steinberg, hearing the others, listening to their arguments, is openly skeptical about the proposition that art and science are fundamentally like each other, that they pursue something of the same purpose, or serve something like the same ends. In the metaphorical sense, art and science can be said to resemble any number of other things; there is no reason, however, to insist on the significance of their putative mutual resemblances. Why, Steinberg asks, "yoke" art and science? What service does such an exercise perform? What is gained by the transaction?

Showing very deep skepticism about those who insist on the utility of such associations, Steinberg explains how fundamentally different is the condition of the artist in today's society from the one that the

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scientist experiences. Since all roles are culturally conditioned, they must never be thought to have a permanent significance. Reminding us that the roles were once almost totally reversed—that the artist was immeasurably more essential to a Christian society than the individual who claimed the distinction of being a scientist—Steinberg sees that no artist can aspire to such importance in modern times. War, as the twentieth century has come to know it, has given new eminence and new prominence to the scientist. Lenin had no great need for the artist; Napoleon, a century earlier, fully appreciated the value of a David or a Roget de Lisle; each served to enhance and justify his power.

Steinberg, looking at the one figure universally acknowledged to be distinguished both as artist and scientist—Leonardo da Vinci—notes how all of Leonardo's scientific work has been superseded; his artistic creation, however, is "unrepeatable, like the life of a man." How can two such different orders of creation be profitably compared?

Listening to scientists who speak of the "elegance" of their experiments and proofs, Steinberg understands their meaning, but knows that the term "elegance" has a very different connotation in art, where it quickly collapses into "finesse or good taste." Almost all the conventional notions of how art and science are bound together—how they provide delight and pleasure for example—are questioned. Steinberg refuses to accept such conventional accolades to "creativity." Instead, he raises the possibility that a good deal of art, far from pleasing, actually provokes fear and distrust, that it does not kindle sentiments of delight that are widely shared. Writing about the "animosity" generated by art, of the physical and verbal aggression that it may incite, Steinberg offers several examples to demonstrate the complex passions raised by individual works of art. If art needs to be set apart from science, if its procedures, practices, services, and validations are all fundamentally different, Steinberg knows that there is no easy way to answer those who wish to believe that all creativity is in fact linked. Almost his last words are, "I find myself ready, more than ready, to take the opposite side of the argument."

If Leo Steinberg's essay came as a direct consequence of the *Daedalus* conference, Susan Gill, completing a manuscript on Oedipus and Daedalus, submitted chapters that included one entitled "The Paradox of Prediction," which is concerned largely with

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hypothesis construction and concept formation. Gill, seeking to distinguish between "explanation," which comes after the fact, and "prediction," which comes before, recognizes that there are limits in the uses of explanation to achieve prediction. In her view, "The arts must respect the systematic methods of science. Science must respect the arts' acceptance of uncertainty, and violation of control as important to concept formation." Each has something to give the other. Surveying various kinds of prediction—the absolute prediction of the physical sciences, the probabilistic prediction of the biological sciences, the possibilistic prediction of future forecasters and conceptual arts practitioners, and the prediction that is wholly uncertain—Gill deals with the problem of invention, the concern of the artificer. Before the scientific era, she reminds us, the concept of prediction was correlated not so much with precision as with vision. The great prophets of the Old and New Testament did not simply foresee future events; they studied conditions in the past and the present in order to recognize possibility. The seer sought to influence the course of events; the oracle's role was not to provide a single answer; his purpose was to stimulate thought, from which a number of alternatives might be discerned.

Gill insists that the challenge of science is to explain what has hitherto been unexplainable and unpredictable; the challenge of the arts is to work creatively, both with mystery and unpredictability. In the study of the human mind, the two must be brought together.

Alistair Crombie, in "Experimental Science and the Rational Artist in Early Modern Europe," provides an account of a time when art and science were united. The "virtuoso" in the Renaissance was the rational artist, designing his intentions by analysis, extending that analysis through his hands. Whether he was mathematician, experimental investigator, artist, or man of politics, he depended on the "rational anticipation of effects." The model for all such effort came from antiquity, Greece. The "cultural style" of the Renaissance and early modern Europe made certain things possible, but precluded neither ignorance nor error. The important thing for Crombie is that the man of *virtù* was a rational being; he showèd his rationality through "knowledge, technique, and continual practice."

Practical art, like natural science, became highly intellectualized, and was precisely controlled. Galileo, in Crombie's system, marks the point of transition between two great intellectual movements, each

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dominated by mathematical rationality, a "transition from the world of the rational, constructive artist to that of the rational, experimental scientist." The scientist and the artist were at one in "their common form of argument, but also in their common use of postulation controlled by practical experience and experiment."

"The invasion of science by art through hypothetical modeling went very deep during the seventeenth century," according to Crombie; it saw natural philosophers join rational artists in communicating to a wider public. Music, like art, became a science, and could be spoken of as such. Indeed, the habit of the nineteenth century, of making a sharp distinction between art and science, was wholly inconceivable in early modern Europe.

So, also, as Europe expanded over the world in the seventeenth century, becoming familiar with the perceptions of new and different peoples, becoming aware also of the variety of nature and geography, the relativity of its own values became apparent. If there was "a dramatic increase in the power, precision, and range of techniques of logical, mathematical, and instrumental analysis," there was also "a stricter and stricter examination of what scientific investigation could be accepted as having established." Probability, more than certainty, began to make its appearance in this increasingly skeptical age.

Gerald Holton's "The Advancement of Science, and Its Burdens" was originally delivered, in a quite different form, as the tenth in the National Endowment for the Humanities' series of Jefferson Lectures. There is significance, certainly, in the fact that, after a decade, a historian of science and physicist should have been asked to speak on a platform previously occupied by scholars more firmly rooted in disciplines conventionally defined as humanistic. Nor is it without significance that Holton began by quoting from Lionel Trilling, citing Trilling's concern with the contemporary "loss of confidence in the power of the mind." This diminished confidence, so very different from the optimism of the eighteenth century, Holton sees as a serious matter, representing as it does, a diminished belief in national possibility. If, at one time, the educated individual might be expected to approve of science, and aspire to understand it, such sympathy is less conspicuous in today's world. One of the ironies of our day may be that many who are among the best educated belong also to the company of those most skeptical of the benefits of science and technology.

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Holton, like Steinberg, is struck by the fear that exists, a fear and resentment not so much of art as of technology. It is strange that at a time when scientists and technology enthusiasts are more committed than ever to their large and bold enterprises, more conscious of what they are accomplishing, that others are fearful, worrying what all these accomplishments are likely to lead to.

When one considers the extraordinary advances that have come since the age of Newton and Bacon, when one reflects on the technological advances of our own day, the benefits seem almost incontrovertible. There has been, Holton writes, "a remarkable symbiosis between the Newtonian and Baconian Programs, and the marriage of science to technology is not only permanent, but appears to be beneficial to both." The advantages, in comforts enjoyed, biomedical and social advances, the development of human rights, and any number of other things cannot be gainsaid. Yet, there is no mass satisfaction. On the contrary, many have little knowledge or understanding of the science and feel almost impotent before the new technology. Citizens, though they enjoy the right to vote, feel themselves powerless. In Holton's view, only an informed and self-confident citizenry can serve as a secure base for democratic processes. "The education of freemen, in science and technology, becomes not something to be desired, but essential to the well-being of the republic."

Howard Gardner's essay, "Freud in Three Frames: A Cognitive-Scientific Approach to Creativity," may, on one level, be read as a study of Freud and his thought processes. On another level, it is an inquiry into all creative processes, seeking to discover whether creativity is the same thing in all fields, whether Samuel Johnson's "true genius" in fact exists. Understanding that there may be in any creative person "a combination of intelligences at work," Gardner finds three principal talents in Freud—linguistic, logical-mathematical, and intra-personal; Freud applied them all in his scientific and clinical work. Starting to do research first in the well-established fields of neurology and neuroanatomy, Freud soon shifted to pursue the study of issues that did not fall within any recognized scientific domain, but belonged instead to the domains of literature, religion, and folk medicine. Attentive to what others around him thought and said, influenced also by the city, Vienna, and the situation of his own life, as a somewhat marginal person, as a medical man, Freud de-

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pended on the collaboration and criticism of his colleagues. These and other institutional factors were influential in his development; they also affected the development of psychoanalysis.

Gardner's interest, however, is not so much in Freud's genius, as it is in the larger and more general question of human creativity. Believing that the possibility of cognitive science moving into a wholly new phase depends very much on such understanding, Gardner sees himself as a pioneer in this new science. His study of Freud's life, based overwhelmingly on the comprehensive Ernest Jones biography, is helpful in suggesting the factors that go into the making of a creative life. Were numerous such case studies one day to exist, it might be possible, Gardner writes, "to propose *models* of the creative psychologist, the creative natural scientist, or (should it prove apposite) the creative person in general."

Gardner, while accepting the utility of biography, recognizes the need for linking all such study to the investigation of certain cognitive processes now being studied by those concerned with artificial intelligence. Greater understanding of creativity will depend on how psychologists, historians, neurobiologists, and others are able to pool their intellectual resources. New kinds of cooperation are called for, if the promise of a new cognitive science is indeed to be realized.

Given what Gardner has written about the prospects for new research in cognitive science, and given what others in this *Daedalus* issue say about certain new investigations of mind and intelligence, it is not surprising that the last two essays deal specifically with information technology, considering its implications for our culture. Daniel Dennett, in "Information, Technology, and the Virtues of Ignorance," while acknowledging many of the more remarkable features of modern technology, and accepting the many ways in which it has improved life, asks, almost poignantly, whether it is not possible that we are moving, imperceptibly, into a world that we will not know how to inhabit, that we will be unable to leave. The possibility that information technology is "poised to ruin our lives," is something that he would have us seriously reflect on. The new technology, Dennett writes, will compel us to leave behind any number of traditions that have so far sustained us. If most individuals seek to live good lives—"good" being defined as interesting, exciting, fulfilling, and happy lives—they aspire also to live moral lives. Dennett believes that past technology may have allowed the individ-

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ual to do both. It is by no means certain that the new technology will permit this. A choice may have to be made between living an interesting life and living a moral life.

Dennett, using medicine and medical care as one example, considers the problems that physicians are likely to confront in the very near future. "Expert systems" will soon be providing information that is now largely unavailable. What, he asks, will happen to the rural doctor, who has conceived of his role in a wholly different way? Such a physician will be unable to ignore the "expert systems," particularly if they provide demonstrably useful information. To ignore such aid would be a form of negligence. Assuming that the "expert systems" turn out to be as good as they are presently advertised, medicine will become a completely different profession. The doctor, in Dennett's view, may soon find himself as being little more than a "health-care doorman." The major social role the doctor has enjoyed in recent decades will be extinguished. While such "extinctions" have also occurred for other professions, without great or obvious loss, if physicians suffer a diminished role, will the society lose, or will it be possible to say that the traditional role was simply not worth saving?

Dennett sees earlier generations as having lived with "unavoidable ignorance"; there are now unparalleled opportunities to know, and these opportunities are quickly translated into "obligations to know." Glutted with information, "common knowledge" is limited, and is always shifting. The contemporary world depends increasingly on advertising for its specific items of information. In Dennett's view, the need today may not be so much for a new technology, as for new "conceptual innovations." The individual, having the time, energy, and knowledge to undertake more than staying alive and sustaining himself, must come to understand that there is a need to deal responsibly with the bounty that exists. Regrettably, there is little knowledge of how to do so, or of what deserves priority. Dennett asks whether our most urgent need may not be for an "Expert System for Moral Advice-Giving in Real Time."

Anthony Smith argues in a manner largely congruent with this. Recognizing that we live at a time of profound change in technology and scientific theory, that these shifts are universal, he insists that an earlier phase in human history is ending. Both the agricultural and the industrial phases are becoming obsolete; the convictions and priorities of an earlier age are threatened with subversion. In his essay,

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"Technology, Identity, and the Information Machine," Smith sees the computer as the revolutionary instrument, information theory as the evangelist. The computer is expected to provide a perfect and recallable memory of everything; its most distinctive feature is its separation of knowledge from the knower; knowledge acquisition becomes a wholly new thing. More than the technologies of transport, production, and extraction—the technologies of yesterday's industrial revolution—information technologies alter our sense of the world, requiring a revision of our views on the position of the species within the dimensions of time and space.

Just as migratory and agricultural societies differed from industrial society, so the information society will differ from all three. We are, in a sense, reexperiencing the Gutenbergian revolution, but with a new technology. If print served to create the notion of the fixity of knowledge, and if this led to a systematization of knowledge, "a standard text," largely unavailable in a script culture, intellectual skills necessarily changed. While electronic culture is not likely soon to displace print culture, any more than print culture displaced script culture, it will make the primary unit of knowledge, the "byte," a statistical entity, completely different from type, which carries with it the notion of "serial logic." We live now with the notion of binary opposition, where binary digital logic becomes all-important.

In the pre-Gutenbergian era, there was an intellectual nostalgia, a yearning for something that had been known and lost. With the coming of print, knowledge became the quest for something in the future. Research, in the modern sense, replaced scholasticism; it was dependent on print. With the electronic era, all certainty of knowledge disappears. There is no longer any ultimate validation of a text, an original writer, an original authority. A new dimension of relativism has entered contemporary culture. The idea of community, in the old-fashioned sense, is almost inconceivable. We are finally changing our image of the world from the Victorian mechanistic model to a modern cybernetic model, based on a new biology and on ecology.

MacLuhan's "global village" is seen by Smith as a great myth; no such community will exist. Indeed, Smith's fear is that we will see a totalitarian culture emerge, a totalitarianism different from the version known earlier in the century, possibly more palatable, but no more free. Like all totalitarianisms, it will begin by falsifying history.

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The universe will be turned into a kind of artifact; human behavior will be said to be representable wholly in the electronic mode. If intelligence can be "artificial," then the randomness of history disappears. Everything is then within our control. That, Smith says, is a profoundly totalitarian idea. In the new information society, whatever its other features, there will be less scope for autonomous action. As doubt is banished, and as those errors once governed by guess and judgement disappear, we will live in an extremely brittle and dangerous world, economically and militarily. For Smith, a fully "technicized environment" corresponds with a fully secularized culture, with no room left for the spiritual. We will have only a very vague notion of what the self once was, of what history once allowed the self to be.

A great debt is owed those who consented to allow us to reproduce certain of the materials that were contained in the original transcript of the *Daedalus* December 1985 meeting. Our sincere thanks go to Stanley Cavell, Leon Cooper, Sam Edgerton, Jr. and Victor Weisskopf. Also, very special thanks are due Dr. Robert Root-Bernstein, who urged us to convene that meeting, and was able to persuade the John D. and Catherine T. MacArthur Foundation to make a small grant that permitted us to assemble many of those who have written for this issue. A very substantial thanks is owed to all our authors. They have produced provocative copy.

S.R.G.

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Leo Steinberg

Art and Science: Do They Need to be Yoked?

Non arabis in bove simul et asino.
—Deut. 22.10

CURIOUS TO LEARN HOW FIRST-RATE SCIENTISTS view their relation to art, I came to listen, wondering how much attention the topic deserved. Science and art are unlike and alike, and unlike again, depending on where you touch down. We can all name certain areas where, historically, science and art overlapped. We can think of ways in which some art, or some function of art, can be said, metaphorically, to be like some science. But why pick on science? Don't any two disciplines offer mutual analogies to a rhetorical imagination? Suppose we brought together around a conference table spokesmen for art and for, say, mountaineering, or aviation: would they not find some intriguing affinities? Braque said as much when he spoke of himself and Picasso as mountain climbers. And Picasso, referring to the same partnership, likened himself and Braque to the Wright Brothers—presumably because Cubism, without fear of flying, had overcome the gravitational pull of perspective. We could compare artists to acrobats: both groups perform with economy and precision while taking on problems of balance in three-dimensional space. But the analogy has long lost its freshness,[1] and one looks for alternatives. So, when Picasso entertained a celebrated torero at his château, he confided that the two of them, bullfighter and painter, were doing much the same thing. On other occasions, Picasso declared that art was like war; or like exorcism. He never said that it was like business, but I am sure

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others have. The comparative term depends on the social context and the promptings of conversation. So why pick on science?

But suppose we agree that creative science is less consistently rational than some people think, and art less irrational, so that the two move somewhat closer together: what (in William James' phrase) would be the "cash value" of such a conclusion? Will it affect Federal funding?

The excellent American abstract painter Byron Browne (1907–1961) wrote: "Like the scientist, the artist is a poet who deals with symbols." Of course, bank tellers too deal with symbols; everyone does. Browne's emphasis, then, has to fall on their being poets—makers in the pristine sense of the word. Unlike bank tellers, artists and scientists fashion coherent symbolic structures to assort with fresh constellations of referents. Their handling of symbols becomes, on this view, a "poetical" enterprise in which representatives of both parties are somehow similarly engaged.

Well, yes and no; they differ in purpose and in the response they elicit. To predict and control is seldom the objective of art; and the findings of science are only rarely regarded as a matter of taste.

When scientists claim to be not unlike artists; when artists (or their spokesmen) say they are operating like scientists, neither group speaks from professional competence. They may be making brotherly or political gestures. More often they are merely breaking the Tenth Commandment: the artist envying science its arcane complexity, its apparent validity and *sine qua non* status in modern culture; the scientist envying art its supposed fancy-freedom, its power to move the heart, and its perdurable glory. Each covets his neighbor's goods. But that's human nature and hardly specific to artists or scientists.[2]

It is sometimes maintained that both science and art, whether in content or methodology, are expressions of the *Zeitgeist*. No doubt. But to the extent that the *Zeitgeist* has any objective existence, it finds expression as well in law and philosophy, in the training of athletes, and the operation of the stock market. The *Zeitgeist* said to be common to art and science is not peculiar to their interrelationship.

Someone will say that art and science have this in common: they interpret the world for us. But is it useful to entertain such notions without regard to the historic condition of science, its mutations from pre-Socratic philosophy to the alchemy of the late Middle Age to state-sponsored research induced by two modern world wars? Does

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a secretive science enmeshed in magic perceive the world "scientifically"? Do natural philosophers in a non-scientific culture interpret the real world? Medieval thought recognized degrees of reality, and judged the intimations of revealed Scripture more real than current things and events. If there was sickness, it was imputed to sin, and the remedy lay in repentance, not in a study of physical causes. Accordingly, the twelfth-century Augustinian Hugh of St. Victor, having little use for scientists, past or present, welcomed the abandonment of their misguided quest:

> The pagan philosophers, in searching out the nature of things with curiosity—that is, in inquiring into the works of creation, have become futile in their thoughts; but Christian sages, by meditating constantly upon [Christ's] works of restoration, drive every vanity from theirs (*Noah's Ark,* IV, 11).

For Hugh of St. Victor it was the promotion of salvific knowledge that mattered, not the peering into unredeemed nature. But that art was a necessity, he would not have doubted, for every altar needed an altarpiece and without altars, how could men be saved? It was a more urgently real world that art was interpreting.

How long did this frame of mind last? Some trace of it may have lingered until 1794, when Lavoisier, about to be guillotined, was told that "the Revolution has no need of scientists." That the Revolution did need a Jacques-Louis David to exalt the martyrdom of Marat, and a Roget de Lisle to write the *Marseillaise* was taken for granted. About 120 years later, Lenin derided artists as "lackeys of the bourgeosie"; scientists he would have honored as indispensable to the cause.

So when we speak diachronically of affinities between science and art, it might be pertinent to distinguish the science of a culture that construes its reality by way of myth from the science of a culture whose chief explanatory instrument is theology; or the science whose supreme authority is a corpus of ancient texts from a culture whose truths, ideally, derive from, or submit to, experimental verification. Even if the condition of art were unchanging, its relation to changeable science would be inconstant. But in fact we are trying to throw a bridge between two moving bodies.

There are other considerations which discourage me from accepting unhistorical art-science analogies. One of these is the psychological

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orientation of the practitioner. It seems to me that there is a potentially crucial disparity between a science pursued by persons in isolation—whose preoccupation tends to remove them from human companionship and whose only spiritual kinship is with similar solitaries enshrined in old books—and, on the other hand, modern scientists who, whether alone or in teams, work within an organized system and in the intervals between professional congresses. The earlier type is exemplified in the proto-scientist Leonardo da Vinci.

The larger of the two Leonardo manuscripts at Madrid contains an astonishing passage (National Library, Ms. I, fol. 6r). Midway in his labors, the author suddenly turns from his exquisite mechanical drawings and left-handed notes to address a haughty apostrophe to mankind. The hauteur is impersonal, for the speaker perceives himself as an avatar in a sustained metempsychosis. Breathing within him Leonardo feels the returning spirit of the rare scientists of past ages and, as their embodiment, he exclaims:

> Read me, O Reader, if you find delight in me, because very seldom shall I return to this world; and you know that the power of such a profession is found in but a few, who seek to compose these things afresh. And come, men, to see the miracles which, through such studies, one can reveal nature.

In these solemn words Leonardo expressed his conviction that the periodic reincarnation of the inquiring mind was infrequent, and in its rarity far more precious than the ability to paint pictures, which after all was well enough represented in the *Arte dei Medici e Speziali* (the Florentine guild that united doctors, druggists, and users of pigments in their common reliance on mortar and pestle). Therefore, like Piero della Francesca before him, Leonardo gave up the painter's drudgery for the sweetness of scientific research.

He had every right to his preferences; but the underlying comparative judgment was, I believe, deeply mistaken. Leonardo saw the inquiring spirit embodied only in solitary revisitants—Grosseteste, Alhazen, Archimedes, etc.—scattered singletons thinly spread over two previous millennia. He did not foresee the time when their spirit would be institutionalized and instilled in thousands who, like trained elite troops, would be put to work in laboratories around the globe, supported by government, industry, universities. Less than five hundred years from the moment he wrote those lines—a time-span not as great as separates him from, say, Avicenna—academies

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worldwide would be turning out annually cadres of Ph.D's who would know far more than he about nature's marvels, and smile at his marvelous engines. Among Leonardo's inventions there is hardly one—from tanks to shrapnel, from two-level highways and rotating bridges to the parachute and the keyed flute—that would not be re-invented and bettered.

The same holds for Leonardo's precocious intuitions of the dynamics of nature. The incidence of marine fossils on mountaintops did not, to his mind, prove the historicity of Noah's Flood; to him it suggested geologic upheavals. And observations of equal boldness crowd his notebooks on scores of subjects, dazzling enough to have placed Leonardo among our top culture heroes. But every one of his correct intuitions has surfaced again independently; not one that was not repeatable; not one insight among them that remained unsuperseded. Whereas there is no Leonardo painting that can be conceived again, and not so much as one fleeting sketch of ball bearings or horses' legs that can be equaled. Unlike his surpassed scientific work, Leonardo's artistic creation is unrepeatable, like the life of a man. One need not conclude that Leonardo's science is, on that account, less valuable than his art (though deep down I believe it). But the value is of a different order. The scientific work may still be admired, but as we admire a brilliant military campaign. We don't fight it again—it is done and finished. Whereas the *Madonna of the Rocks* lives out its duration unscathed by progress. Does not this distinction point to a difference that overwhelms any incidental analogy between science and art?

At this table, three criteria have been proposed to characterize the products of art: involvement with the specific materiality of things; elegance in composition; and the emotion of delight. It seems to me that each of these is problematic. The question of art's relation to materiality has lately grown somewhat intractable in view of developments such as conceptual art. It demands philosophical thinking, like Arthur Danto's. The subject is interesting and important, but too large for the present.

As regards "elegance," it is commonly pointed out that scientific equations have not only explanatory force or truth value, but that the formulation itself, in its exactness and spareness, may be a source of

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delight, quite akin to aesthetic pleasure. Whence it would follow that the aesthetic criterion of "elegance" pertains also to science.

I suspect this claim to be a disservice to scientists. Those among them who glow when they discourse upon elegance have more in mind than the "scientific precision, neatness and simplicity" which Webster's III gives under *elegance,* definition 1d. For physicists and mathematicians, the word, as I understand their use of it, points ultimately to a satisfaction of the deepest kind. Contemplating a genial equation, they seem to perceive a fit which reconciles their symbols, their professional instruments, with unknown processes, confirming that the two, the receding out-there and the tools in hand, are essentially friendly, commensurate, and amenable to each other. The adept who sees what is encompassed in an admired equation experiences it like a contract, a truce, and stands by like a celebrant at a marriage. The analogy that occurs to me is with the formulation of dogma at early Church Councils, when the minutest deviation from correct wording threatened error and heresy. What had to be worded was recondite—nothing less than the triplicity of Persons within the absolute unity of the godhead, or the Paraclete's mode of procession. Could anything be more remote from our tool chests than "the mysterious foundation of God"? And when the right formula was attained, when the vast inaccessible everlasting was at last neatly stacked, it was received with such exultation that theology, the discipline that furnished the symbols, was raised for a thousand years to the status of Queen of the Sciences. May I suspect that modern scientists feel a similar exultation when they rejoice at the "elegance" of an equation?

The trouble with the word "elegance" is, however, that in its application to art it collapses to the more conventional meaning of finesse and good taste. And few of the artists I have known would accept these connotations as a defining condition of art. If I resist the invocation of "elegance" to connect science and art, it is because I take it to be little more than a verbal trap.

I should perhaps add that if my assessment of the scientists' feeling for elegance is too high; if the concept to them means no more than Webster's "precision, neatness and simplicity"—qualities some of us look for in dress—then "elegance" becomes even less apt to furnish an exclusive linkage with art. For in the Websterian sense of the word there is hardly a human activity, from making omelettes to making

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apologies, that may not be attended by elegance, more or less. De Quincey found even murder to qualify, arguing in a mock lecture that murder had its aesthetic side. (What a delicious context for the first English use of "aesthetic"!)[3] And we still speak of "the perfect crime." If elegance is what the sciences share with art, then they share with art only what they share with all human performance.

Thirdly, regarding delight considered as a defining norm. To begin with, delight is such a pervasive emotion that it is difficult to reserve for the experience of artifacts. (The other day, having my teeth cleaned at the dentist's, I passed the time watching the hygienist's young eyes. They kindled delight in mine, but let that pass.)

What do we mean when we associate works of art with "delight"? Do we mean the delight to be had in experiencing them, or the artist's subjective feelings in the course of creation? Either way, the proposition leaves me uneasy. No one doubts that one may take pleasure in performing a task, or even in merely doing what one is trained or accustomed to do, or has chosen to do. But it is precisely in the creation of serious art that the subjective mood is as often one of torturing doubt and obsession. Read Balzac's story "Le Chef-d'oeuvre Inconnu," where an artist's struggle to attain what he thinks his painting should be leads to madness and death; then read how Cézanne wept upon reading the story, identifying with its archetype victim. And read, finally, Picasso's remark that what matters most to us in Cézanne, even more than his painting, is his anxiety. When we consider the dire compulsions under which some of our most cherished works of art were produced, then the artists' "delight" in their making seems, as a defining characteristic of art, a misnomer. The word, if not the concept, sits too close to the delectations of entertainment.

But, you say, we delight in the outcome. Again, yes and no. I happen to be one of the millions who delight in certain art works. But there are probably billions who pass in total indifference what delights us, or else relish only the kind of art that my fellow millions would not call by that name. Viewed from our elitist position, which makes excellence a defining trait of the class, it is not art that those others delight in; just as devotion to folk astrology would not, in present company, qualify as love of science. It has to be good science to rank as science at all.

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But indifference to art is only the least of it. More revealing of art's innermost nature is the animosity it is capable of arousing—and the aggression. This ill-will is too endemic to be discounted as accidental. If we suppose iconoclasm to be flourishing only by fits, we are mistaken. The common perception of it as a series of disorderly episodes reflects merely our inattention. In the full range of its manifestations, from outright destruction to censorship, iconoclasm is a perennial accompaniment to the history of art. It is spectacularly at work in our own century.[4]

I would like to discuss this matter at some length, even though it has no direct bearing on art's relation to science. But that is the very point I hope to be making: that what is special to art, to wit, its reception, puts it beyond the reach of comparison.

Three years ago, I wrote in another context:[5] "The modalities of iconoclasm are various, as are the objects of its execration. The grounds may be doctrinal (as in the classic Byzantine phase); or socio-political (as in the destruction of royalist imagery by revolutionists); or ideological (as in the proscription of 'decadent' art under Hitler and Stalin); or moralistic (as in the zeal of the censor); or entrepreneurial (as in site clearing for urban development and renewal); or gustatory, the deadliest ground of all, since nothing endangers a work's survival more than a recent aversion of taste.

"In the past, works of art have been destroyed by avarice or sudden need, as when the production of goldsmiths was melted down for the metal, or bronzes were cast into cannon. And always, in past times as now, there is the attritional work of neglect presiding over the crumbling of structures that need care to survive. The dispassion of cold indifference is a prime killer, like Baudelaire's *ennui*. More positive passions come into play periodically: a rage against art as evidence of the unconscionable luxury of the rich;[6] fear of the magic of images—which accounts for eyes gouged out on painted figures; or the sheer exhilaration of vandalism. It seems to me that mankind's commerce with art is a yes/no affair, of which standard art history gives a lopsided picture."

Not surprising, though rarely discussed, is the often destructive hostility of artists themselves, that is, the animus of modern artists toward foregoing art which is felt to stand in their way: "The young who now crave attention resent ancestor worship. Their indifference to senior art can be chilling, their antagonism implacable. And this is

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why engaged artists swell the ranks of those other zealots who form the wreckers' procession .... The destruction of works of art emerges as an ongoing cultural enterprise, pursued at all times with a sense of enormous accomplishment: remove the blight and the world will be the better for it. Iconoclasts jubilate like angelic hosts at the Church's burning of heretical books."

The scholar who is now doing the most probing work on the subject, with concentration on representational images, is David Freedberg.[7] Writing of the iconoclastic fury in the Netherlands (1566), he observes that the destructive movement no sooner began than it "caught on like a craze." (The same had been true in Calvinist Switzerland, and would recur in Puritan England.) In other words, the hostility was stored up, waiting only for community support to break forth; much as periodic outbreaks of social violence—lynchings, pogroms, or the "Packy-bashing" in modern London—indicate deposits of racism and xenophobia. Art thus distinguishes itself among artifacts by attracting passions of the kind normally reserved only for fellow men.

Freedberg's close study of anti-art violence, past and present, individual and collective, has led him to a disturbing conclusion: that we misjudge our own, normally civil response to images if we dismiss the recurrent assaults upon them as due to mental derangement, unrelated to our own states of mind. He argues that the response to images, from the "normal" to the fanatic and the insane, is of a piece; that we love and hate Art in a psychic continuum—and I agree.

Think of the enmity incurred by modern art, for which we tend to lay part of the blame on the provocative character of the work. But Francis Haskell points out that the mood has been seething for more than a century and a half, and that its vehemence remains to this day somewhat mysterious:

> In 1815 an English writer observed that there had been "a *virulence of Criticism* on the pictures painted by *Turner,* such as should be reserved for Crime, but wholly disproportioned to a subject of painting however much disapproved." In the Chambre des Députés in Paris in 1912 a socialist deputy demanded that measures should be taken to prevent Cubists exhibiting at the Salon d'automne . . . because "it is absolutely inadmissible that our national palaces should be used for manifestations of such an obviously anti-artistic and anti-national kind."[8]

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Similar sentiments were to be voiced, and acted on, by Nazis, communists and conservatives in common cause down to the 1950s and 60s—in Germany, the USSR, the US. Shall all these historic smarts be declared incidental, and be plastered over by honeying definitions of Art-in-general, thick with "delight"? Must art-as-such still be defined to agree with old pieties, without acknowledging its mixed reception?[9]

And lest modern art be thought to have gained a monopoly on hostility, consider the case of the English suffragist Mary Richardson, whom the London press in 1914 dubbed "Slasher Mary." She was an art student in her mid-twenties, a veteran of more than ten hunger strikes in Holloway Prison, and an ardent follower of Mrs. Pankhurst, then believed to be dying in that same prison. Visiting London's National Gallery, Mary Richardson stopped before a picture which had been recently acquired for the nation—Velázquez's *Rokeby Venus*. She drew an axe from her satchel and drove it into the canvas eight times, twice twisting the blade in the wound before withdrawing it for the next slash; and so continued until stopped by the guards. In the statement she gave to the press, she said that she loved art, but had "tried to destroy the picture of the most beautiful woman in mythological history as a protest against the Government for destroying Mrs. Pankhurst, who is the most beautiful character in modern history. Justice," she added, "is an element of beauty as much as colour and outline on canvas. . . ."[10] On these high principles she justified her aggression against the loveliest nakedness ever painted. Thirty-eight years later, being interviewed by a reporter for the London *Star* (February 22, 1952), Richardson confessed to another, a non-political motive: "I didn't like the way men visitors to the gallery gaped at it all day long."

For just how long, or with what odious symptoms, those male gallery visitors actually looked at the picture, we'll never know. But Mary Richardson thought—or remembered nearly forty years later—that they gaped at it; or let us say the picture had *made her think* that they leered at it in a certain way.

Turn now to Titian's *Venus of Urbino* and to the response it drew from a man who probably never lifted a finger to damage a work of art: our darling author of *Huckleberry Finn:*

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At the door of the Ufizzi *[sic]* in Florence, one is confronted by statues of a man and a woman, noseless, battered, black with accumulated grime,—they hardly suggest human beings—yet these ridiculous creatures have been thoughtfully and conscientiously fig-leaved by this fastidious generation. You enter, and proceed to that most-visited little gallery that exists in the world—the Tribune—and there, against the wall, without obstructing rag or leaf, you may look your fill upon the foulest, the vilest, the obscenest picture the world possesses—Titian's Venus. It isn't that she is naked and stretched out on a bed—no, it is the attitude of one of her arms and hand. If I ventured to describe that attitude there would be a fine howl—but there the Venus lies, for anybody to gloat over that wants to—and there she has a right to lie, for she is a work of art, and art has its privileges. I saw a young girl stealing furtive glances at her; I saw young men gazing long and absorbedly at her; I saw aged, infirm men hang upon her charms with a pathetic interest. How I should like to describe her—just to see what a holy indignation I could stir up in the world . . . . yet the world is willing to let its sons and its daughters and itself look at Titian's beast, but won't stand a description of it in words . . . . There are pictures of nude women which suggest no impure thought—I am well aware of that. I am not railing at such. What I am trying to emphasize is the fact that Titian's Venus is very far from being one of that sort. Without any question it was painted for a bagnio and it was probably refused because it was a trifle too strong. In truth, it is a trifle too strong for any place but a public art gallery.[11]

Don't you hear the hiss of venom at the words "art" and "art gallery"? Mr. Twain offered no violence; it would not have been in his character, and besides, he was a tourist abroad. But observe: the picture *induced* him to watch a young girl, some young men, and some aged; it *made* him want to describe it in order to raise worldwide indignation; and it *angered* him by arousing "impure thoughts," not in him, but in those others he had been watching. How like Slasher Mary, who would put into action what he put on paper. Both responded to what they thought the picture was *doing*—to others, of course.

One more case history: Sometime in the 1950s, a visitor to the museum in Toledo, Ohio, gashed two pairs of eyes in a sixteenth-century Dutch double portrait, a work by Dirck Jacobsz. The picture presents the artist's elderly father, Jacob Cornelisz., himself a painter of stature, in the act of portraying his wife. The latter, though present only in effigy, is scaled like her husband, and both faces, that of the portraitist and the woman's face on the canvas, stare straight at the

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beholder. But who *is* the beholder? The depicted moment allows for no doubt: the painter, with palette and poised brush in hand and looking out of the picture before administering the next touch, is scrutinizing his model, his life's companion. And that puts the beholder—me, myself visiting the museum—in the place of Jacob Cornelisz.'s wife! Or rather, since I am not his wife, it stares me out of sight, since under the circumstances she alone can be the target and

Dirck Jacobsz. *Portrait of the Artist Jacob Cornelisz. and His Wife,* after restoration. Courtesy of the Toledo Museum of Art.

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mirror of Cornelisz.'s gaze. She alone is where I am, leaving me nowhere at all. The picture is transitive—it bespeaks my nonentity—it disappears me. Am I to suffer such annihilation? Out with those eyes!

Given its power to disturb the beholder in his self-awareness, the Toledo picture is remarkable, but not unique. Many images set themselves up as the other pole in a situation of reciprocal consciousness. More important, their effective address need not depend (as it does in recruiting posters) on tricks of eye contact, fixed gaze, hithering index finger, etc. A work's capacity to place or displace the viewer, to send forth reassurance, summons, accusation or exhortation, may reside in its total structure. And the imaginative, or the irritated response to its presence is primitive and animistic, as if each of its parts were empowered. Think of Rilke's response to the challenge of a battered Greek torso in a Paris museum ("Archäischer Torso Apollos," Paris, summer 1908). The poet perceives that the loss of the statue's head, "wherein the eyeballs (Augenäpfel) ripened," has not blinded what remains of the body. On the contrary, it is as if the eyes' optical capability had receded inward to suffuse shoulders and breasts and loins, so that now every point on the torso's surface sees you—"denn da ist keine Stelle, / die dich nicht sieht." And what follows is the abrupt sequitur of the poem's five

Dirck Jacobsz. *Portrait of the Artist Jacob Cornelisz. and His Wife,* details, damaged state. Courtesy of the Toledo Museum of Art.

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final words: "You must alter your life" ("Du musst dein Leben ändern"). Not as you were, friend; the torso is watching.

As physical objects, works of art, while they last, have their objective existence, their chemistry. As historical vestiges, they have provenance and documentary or educational value. As *objets de vertu,* so long as taste is on their side, they have price and possessors. But as benign or malignant powers impinging on excitable imaginations, agitating a dubious ether-like medium halfway between what is and is not, they are active objects that may be demonically inhabited and need taming; their place being midway between the inanimate and the ensouled, conscious, intrusive life.

The animistic charge of art works—the vitality imputed to them by the receiver—this vitality is, I think, what sets art apart, and so dissociates it from the propositions of science that any procedural similarity between what artists and what scientists do pales into insignificance.

On the other hand.

Shifting position, I find myself ready, more than ready, to take the opposite side of the argument. It's that kind of problem.

ENDNOTES

[1]In a lecture delivered in New York, c. 1952, Meyer Schapiro traced the tradition of the artist's self-identification with the acrobat: from Baudelaire's prose poem "Le Vieux Saltimbanque" (published posthumously in 1869) and E. de Goncourt's *Les Frères Zemganno* (1879), to Cézanne and Picasso.

[2]Cubism inspired André Salmon to announce, in 1912, that "painting was becoming a science, and not one of the less austere." The enthusiastic response of some early twentieth-century artists to advanced geometric theories of the nineteenth century is the subject of Linda Dalrymple Henderson's *The Fourth Dimension and Non-Euclidean Geometry in Modern Art* (Princeton: Princeton University Press, 1983). The book should be read with its brilliant review by Arthur C. Danto in *The Print Collector's Newsletter,* 16 (May–June 1985), pp. 64–66. "Henderson's book," writes Danto, "is a marvelous demonstration of how scientific ideas are received and transformed by minds not especially disciplined to comprehend them in their own terms but capable of being rocked by vivid metaphorical possibilities . . . . What these geometries appeared to promise, in brief, was confirmation of inflamed aspiration for alternative realities, new logics, new modes of being and human fulfillment, which, when placed alongside the 'fire in the hearts of men' for revolutionized forms of political existence and moralized social orders, must mark at least the first half of our century as a period of the most intense longing for another world since the Middle Ages." Danto's

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sole reservation about this book "of stunning originality and importance" is that the author is not fully aware "how wildly off the mark some of her artists really were"; or that "what Duchamps says about Dedekind cuts or Lissitzky about imaginary numbers is mostly *blague*."

[3]Thomas De Quincey, "On Murder Considered As One of the Fine Arts," 1827: "People begin to see that something more goes to the composition of a fine murder than two blockheads to kill and be killed .... Design, gentlemen, grouping, light and shade, ... are now deemed indispensable to attempts of this nature ...." Turning to general theory, De Quincey's lecturer continues as follows: "Everything in this world has two handles. Murder, for instance, may be laid hold of by its moral handle ... and *that,* I confess, is its weak side; or it may also be treated *aesthetically,* as the Germans call it, that is, in relation to good taste .... When a murder is in the paulo-post-futurum tense, and a rumour of it comes to our ears, by all means let us treat it morally. But suppose it over and done, ... why, then, I say, what's the use of any more virtue? ... Virtue has had her day; and henceforward, *Vertu* and Connoisseurship have leave to provide for themselves. Upon this principle, gentlemen, I propose to guide your studies, from Cain to Mr. Thurtell. Through this great gallery of murder, together let us wander hand in hand, in delighted admiration, while I endeavour to point your attention to the objects of profitable criticism."

[4]See David Freedberg, *Iconoclasts and Their Motives* (Maarssen, The Netherlands: Uitgeverij Gary Schwartz, 1985), pp. 20–21: "The phenomenon has been much more widespread than most people might acknowledge, and taken together [the destructive acts] constitute rather an alarming list." Freedberg proceeds to cite some of the works that have been assaulted since 1956: in that year the *Mona Lisa;* in 1958 Raphael's *Sposalizio* (Milan); in 1959 Rubens' *Fall of the Damned* (Munich); in 1962 Leonardo's Burlington House Cartoon; in 1972 Michelangelo's *Pietà;* in 1974 Rubens' *Adoration of the Magi* (Cambridge); in 1975 Rembrandt's *Nightwatch* (Amsterdam); in 1977 the appalling series of acid attacks on twenty-three paintings in Germany, beginning with Klee's *Goldfish* in Hamburg, through Rubens' *Archduke Albert* in Düsseldorf, the *Martin Luther* and other Cranachs in Hanover, and ending with four paintings by and around Rembrandt in Kassel; in 1978 Poussin's *Adoration of the Golden Calf* (London); and the knifing of Van Gogh's *Berçeuse* in the Stedelijk Museum (Amsterdam). Freedberg's list is a sampling: he does not mention the assault on Picasso's *Guernica* in 1974. Consider also that most museums prefer not to publicize acts of vandalism for fear of encouraging imitators.

[5]Leo Steinberg, *The Sexuality of Christ in Renaissance Art and in Modern Oblivion* (New York: October/Pantheon Books, 1983), Excursus XXXI.

[6]An anonymous essayist wrote in *The Atlantic Monthly:* "We are in the earlier stages of a war upon property, and upon everything that satisfies what are called the higher wants of civilized life. The workingmen are taught to regard works of art and instruments of high culture, with all the possessions and surroundings of people of wealth and refinement, as causes and symbols of the laborer's poverty and degradation, and therefore as things to be hated"; "Certain Dangerous Tendencies in American Life," *The Atlantic Monthly,* 42 (October 1878), p. 393.

[7]In addition to Freedberg's study cited above, see also his "The Structure of Byzantine and European Iconoclasm," in *Iconoclasm,* ed. Anthony Bryer and Judith Herrin (Birmingham, England: 1975), pp. 165–77.

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[8]Francis Haskell, "Enemies of Modern Art," *The New York Review of Books,* June 30, 1983, p. 19.

[9]A useful neologism might be *echthrogeny*, literally the begetting of enemies, as teratogeny means the formation of monsters, or of monstrosities. Art, then, is distinguished by its partly echthrogenous character.

[10]Quoted in Freedberg, *Iconoclasts and Their Motives*, p. 15.

[11]*A Tramp Abroad,* 1880. Mark Twain's squalid provenance for the painting is illusory. Titian's *Venus* was commissioned early in 1538 by Guidobaldo della Rovere, Duke of Camerino and future Duke of Urbino. In the Ducal Palace at Urbino, it was seen by Vasari. In 1631, it passed by heredity to the Dukes of Florence.

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Susan P. Gill

The Paradox of Prediction

ARE THE ARTS AND SCIENCES TWO CULTURES OR ONE? I will suggest that the arts and sciences are one culture to the extent that similar creative mental processes operate both in the formulation of hypotheses in science and in concept formation expressed through works of art. But they are two cultures, with an impassable rift between, when either attempts to explain (by its own methods alone) the operation of that inventive process in both fields.

In studies of the human mind and its invention process, those who would construct theories eventually arrive at a paradox when asked how the theory they have proposed predicts results that can be verified or refuted. This is why humanists study the invention process, but it remains a domain into which scientists seldom dare venture. By gathering historical examples, observing or analyzing individuals whom society has termed "creative," the humanistic scholar can generalize from the evidence he has gathered and perhaps formulate a hypothesis to predict how the human mind tackles creative problems. The method by which the humanist constructs his theory is clear. But when asked if he has done what any responsible scientist should do—provide his theory with the means by which its predictive power can be verified and refuted—he is generally at a loss.

Nelson Goodman clarified the problem of prediction:

> The problem of the validity of judgments about future or unknown cases arises, as Hume pointed out, because such judgments are neither reports of experience nor logical consequences of it. Predictions, of course, pertain to what has yet to be observed .... What has happened poses no logical restrictions on what will happen.[1]

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Hume suggests that prediction accords with past regularity. Prediction-making, like the invention process itself, relies heavily on finding connections and making analogies, on the recognition of implied pattern. Following a linearly causal chain of inference is related to pattern recognition.

If a theory of invention were able to predict the results of that process, it would be verifiable (or refutable). Yet, the basic characteristic of the process is its ability to absorb accident, to resolve inconsistency, and to create with contingency, its intrinsic unpredictability. This is where the arts and sciences, by failing to recognize the paradox their two cultures have imposed upon each other, have been unable to define a coherent collaborative approach to the study of hypothesis construction or concept formation in either field.

EXPLANATION VERSUS PREDICTION

An explanation describes a phenomenon after the fact. A prediction, according to the traditional scientific connotation, characterizes a phenomenon such that its behavior can be anticipated *a priori*. Are explanations just the means by which we make predictions? Or is there a subtle difference? The complementary relation that both explanation and prediction share with contradiction is clear: a single counterexample to a theory will invalidate its explanation, cancel its prediction. But this does not prove that explanation and prediction are equivalent. In order to demonstrate that, one would have to agree that all explanations predict, and that all predictions explain. They do not.

Darwin's theory of the origin of species through variation and natural selection can be used to clarify the distinction between explanation and prediction. That theory explains the *selection criteria*[2] by which new species come about, but no scientist ever used it to predict the future evolution of novel creatures. However, when Australians used myxomatosis to control the rabbit population, Darwinian principles enabled forecasters to predict that a new strain of rabbits would become dominant with increased resistance to the disease. It did. Similar predictions of microorganisms' new resistance to antibiotics, for example, proved Darwin's theory of natural selection to be correct.[3] What is the distinction between the domain in which Darwin's theory could forecast successfully and that in which it could only explain after the fact?

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In both cases, evolutionary development involved accident. But in the case of the rabbits and microorganisms, the type of accidents that would be selected and assimilated was known; nature's *local selection criteria* were established. In the case of new unimagined creatures, criteria for selection were not established. The mysterious emergence of AIDS provides an example. If we know why such a disease can be selected for, why it survives, we know what it is. Or better yet, we would have been able to predict its possible emergence. To the extent that *local selection criteria* can be established in a closed system, prediction of global structure is possible. This concurs with biologist Jacques Monod's thesis that the evolutionary development of the biosphere is compatible with first principles but not deducible from them. In other words, it is explicable but not predictable.

The example of Darwin's theory has illustrated the limitations of explanation for prediction. The question of the limits of prediction *vis-à-vis* explanation is more simply explained. The phases of the moon can be predicted without understanding how it rotates about the earth or reflects the light of the sun. The passage of the seasons was predicted long before the cause was understood, because men were able to recognize repeating patterns. So prediction does not imply an underlying explanation, though it does imply recognition of certain patterns—those relevant to the nature of the prediction.

It is generally agreed that, from a cognitive perspective, there is little difference between retrodiction (the reconstruction of the past), explanation, and prediction (the construction of the future), since all require completing the pattern implied by partial information. However, there is one difference: prediction points in the same direction as the arrow of time in evolution and thought. While we are moving away from the past events we attempt to retrodict or explain, we are moving toward the events we predict. So prediction has a temporal correlation with the process of invention, which retrodiction and explanation do not share.

Concern with rigor and accurate prediction has often pushed psychologists trying to understand human capacity for invention toward local experimental studies and away from the risk of global theory. Their small investigations often fail to converge; they remain isolated. The discipline of psychology has tended to focus its investigations on problems of detail, hypotheses that can be tested and verified. Where prediction is expected, it is not surprising that

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experimental cognitive psychologists, wanting clear, indisputable results, tend to restrict their studies to circumscribed questions. Their experiments are closed systems; the open-ended system of mental inventiveness (with its inherent unpredictability) is ruled out. So the cognitive scientist can flash a little red light or an image to test his subject's reaction time, because this is measurable and predictable. The storage of an image requires microseconds and is therefore testable in the laboratory. Major intellectual revolutions have begun with attention to small detail. Just as Copernicus, in his investigation of discrepancies in the positions of the planets from their predicted positions, paved the way for the heliocentric hypothesis, so cognitive scientists' chronometric studies may open the gates to theoretical breakthroughs.

But creative problems have long histories, uncertain components, and unknown (i.e., unpredictable) results. This is why, though the scientist makes use of invention in hypothesis formulation and theory construction, he cannot study the process by scientific methods alone. For studies of mind, the two cultures, science and the arts, must become one again. The arts must respect the systematic methods of science. Science must respect the arts' acceptance of uncertainty and violation of control as important to concept formation.

THE FOUR FACES OF PREDICTION

The traditional use of the term in physical science suggests that prediction is both absolute and passive. But closer examination suggests that prediction is associated with four connotations, characterized as:

absolute	(passive)
probabilistic	(passive)
possibilistic	(active)
uncertain	(active)

The first connotation is associated with the testing of hypotheses and theories in the physical sciences: prediction is generally assumed to be absolute and passive. In physical sciences ruled by absolute laws, a theory is tested and possibly refuted by finding a counterexample that contradicts the theory's prediction. The term "contradiction" is here not used in the strict logical sense—*p* cancelled by not-*p*—but rather

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in the sense Piaget termed "dialectic contradiction": a general statement or theory is contradicted by a single tiny false detail, or a particular counterexample. This is not the perfect dynamic equilibrium of logical contradiction; all parts of the theory may not be cancelled. But its validity as a whole is cancelled.

The task of a scientific theory is clear: it must explain; it may predict. In either case, it will be subjected to the traditional scientific test of verification through possible refutation. But this I suggest, in the case of theories that attempt to explain the process of invention, leads to a paradox. The demand that a scientific theory predict has been a stumbling block to any serious study of invention.

The second connotation of prediction is associated with the construction of rules in the biological sciences: it is probabilistic and passive. As Ernst Mayr has pointed out, seldom can biology boast the certainty of absolute laws. For this reason, prediction has a different meaning in biology from the physical sciences. While theory-building in the physical sciences generally demands that prediction anticipate with absolute accuracy, in biology its accuracy is usually statistical rather than absolute; prediction may have different assigned levels of probability.[4] Evolutionary theory asserts the independence of prediction (*a priori*) and explanation (after the fact), forging the necessary links between the concept of prediction and that of probability.

Prediction in both of the above connotations is passive: the event predicted will come to pass (or not) independent of whether the prediction is made or not. It is assumed that the prediction is independent of the context observed, that it exerts no influence. Prediction also has an active connotation, which suggests that the fact of making a particular prediction may influence the outcome of future events.

The third connotation of prediction, here termed *possibilistic* and *active,* was historically associated with the prophetic arts. Today it is associated with "future forecasting" and the conceptual arts. The substitution of the term was deliberate on the part of those who did not want their *possible* scenarios to be mistaken for absolute predictions. Future forecasting derives much of its methodology from the statistical methods of the biological sciences. Its analytic aspect aims to be statistical, while its constructive, scenario-building aspect is more akin to the conceptual arts. Like biological prediction, future forecasting acknowledges the importance of contingency. But, unlike

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the general use of the term in biological science, here prediction is *active*; whether this fact is acknowledged or not, present forecasts become part of the data base from which future forecasts are made. Both the prophetic and conceptual arts are concerned with revealing possibility.

Thus far, introducing the first three connotations of the term prediction has suggested a progression from absolute certainty in physical science to probability in the life sciences to the possibilistic speculation of the arts. The very notion of such a progression is an illusion; there is no such spectrum with physical science sitting solidly on one end and the arts teetering speculatively on the other. The *paradox of prediction* lies in the circularity of our argument, through which science and the arts emerge not as two poles, but as part of the same loop.

The fourth connotation of prediction is *uncertain* (emergent) and *active*. Our first connotation was the ideal class, prediction without qualification, perfectly pointing to future events. This fourth connotation is the null class, prediction unable to predict. Why do we need a null class? First, because it is here that the essentially unpredictable inferential leaps (sudden insights), which C.S. Peirce called "abduction," belong. Second, the null class is necessary to show the fundamentally paradoxical nature of the concept of prediction itself; this null class loops back to contradict the perfection of the ideal class. Finally, this fourth connotation clarifies the link between the concept of prediction and the process of invention we shall sketch.

The first connotation of prediction aimed to reveal pre-existent truth; the second and third connotations combined revelation with varying degrees of emergence (contingency that is unpredictable); this fourth connotation concerns emergence of something that did not pre-exist.

A paradox is a logical progression that circles back to contradict one of its premises. This discussion loops on two levels: the *content* of prediction, and the *concept* of prediction. We have suggested how the *content* of a prediction can play an active role, influencing the events it predicts. The *concept* of prediction (meta-level) is subject to the same reflexivity. Our progression in defining the four connotations seems straight and logical. But when the fourth connotation turns back to unhinge the absolute premises of the first, we realize that science and the arts are not opposite poles but rather run on the

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same loop. Since defining is itself an "invention process," the fact that it reflects this characteristic should come as no surprise. The *paradox of prediction* underlies the process of invention.

Marvin Minsky recounts that a famous mathematician, when warned that his proof would lead to a paradox if he took one more logical step, replied, "Ah, but I shall not take that step." Minsky comments: "The Consistency that Logic absolutely demands is not otherwise usually available—and probably not even desirable!—because consistent systems are likely to be too weak . . . . I cannot state strongly enough any convinction that the preoccupation with consistency, so valuable for Mathematical Logic, has been incredibly destructive to those working on models of the human mind."[5] C.S. Peirce would probably have agreed with Minsky. He felt the terms deduction and induction did not cover adequately the mental activity of the creative scientist who must make inferential leaps. He introduced a new term to account for this process: "abduction." To paraphrase Peirce: The first stating of a hypothesis, whether as a simple question or with any degree of confidence, is an inferential leap that I propose to call "abduction." Induction is the operation of testing the hypothesis; deduction proves that something must be a necessary consequence of the hypothesis. But it is abduction that makes the inferential leap and introduces a new idea. However man may have acquired his faculty of divining the ways of nature, it has certainly not been by a self-controlled critical logic. Man has a certain insight, which enables him to form correct hypotheses.[6] This argument will suggest that the inferential leap that introduces a new idea is akin to the fourth *uncertain, active* connotation of prediction: both are emergent processes.

In the first passive connotation, prediction and contradiction are complementary; in the second passive connotation, prediction and probability are complementary; in the third (active) connotation, prediction depends upon the interpretation of ambiguity; and in the fourth, prediction is emergent.

A general theory predicts (either absolutely or probabilistically) the behavior of phenomena in the specific instances it covers. But when one instance contradicts the prediction, the theory must be abandoned or transformed to take account of this larger context. So contradiction and contingency make constant demands on prediction, transforming it from passive to active. Interpretation moulds it;

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emergence extends it. Prediction seen in this way is no longer a static "thing," but an evolving model, a representation of our understanding. Though prediction implies looking ahead, a theory is an explanation based on our understanding *now*; what it predicts for the future depends upon what we understand in the present.

Realizing that we can only act, think, predict, or invent in the present is critical to understanding the characteristics of invention. The distinction between prediction (*a priori*) and explanation (after the fact) is related to a further distinction between *selection critera* and *goals*. Explanation operates in the present, as do *selection criteria*, patterning information that is currently available. Prediction and goal-setting attempt (with the partial information of the present) to construct models of the future.

We like to think absolute control characterizes the scientific method. But absolute control rules out uncertainty, and questions. Are creative discovery and invention not rather more like a camper looking for a box of matches with a flashlight in the dark? When he is in perfect control (i.e., immediately able to shine the flashlight directly on the object of his search), then we can assume he did not need to find it. He already knew where it was. In all other cases his question is, "Where could my matches *possibly* be?" The camper's flashlight must hit the object by accident, enabling him to *recognize* it. But the camper poses his questions (shines the flashlight) selectively, choosing categories of accidents that have promise. He does not shine the flashlight in the trees if he recalls that he left the matches on the ground.

Demanding that a theory of invention predict the path or results of that process is unreasonable for the same reason that setting goals for the creative aspect of that process is impossible. If in fact the process is creative, it must be capable of discovering or inventing something that it could not anticipate in advance. Or, if it can state clearly what it will invent, the creative challenge in that case is to figure out how. Stating the aspect to be invented as a goal implies creating a construct that (in the present) you do not yet have the necessary information or tools to construct. You simply cannot construct it. To avoid semantic confusion we should note that in the case of the camper, his goal should be stated not as "finding the box of matches" but rather as "finding *the location* of the box of matches." The location is what he does not know and cannot state until he finds it. He uses his *selection*

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criteria to pose plausible questions to the problem context, hoping through the combination of selective questions and accident to find his matches. Through his sequence of questions he ambushes his object by eliminating possibilities until he finally hits on the correct answer. This simplified analogy could be misleading: the camper operates solely through a process of elimination; he will receive only "no" answers to his questions, until a "yes" reveals the matches.

Our first passive connotations of prediction say: If this . . . then (certainly or probably) this. The challenge of science is to predict what has hitherto been unpredictable. Thus far we have considered the ability of a prediction to specify that such and such is or is not going to happen (either with absolute certainty or with some degree of probability). We have discussed the complementary relationship between prediction and contradiction. The two passive connotations of prediction are generally taken to cover the meaning of the term. But as we sketch the connection between the concept of prediction and the process of invention, we need to concentrate on the two active connotations of prediction, first as possibilistic and second as uncertain (emergent).

PREDICTION AND POSSIBILITY

The third connotation of prediction introduced the *active* interpretation of ambiguity. As we consider prediction and possibility, we should recall that the concept of prediction itself has changed as the rift between the arts and sciences has widened in the scientific era. Prediction, as currently used with reference to scientific theory, implies that the successful theory must point to *precise* results (whether absolute or quantitatively probabilistic). But before the scientific era, the concept of prediction was correlated not with precision, but with vision. The great prophets of the Old and New Testament did not simply foresee future events; they studied the traditions of the past and the conditions of the present in order *to recognize possibility*.

The prophets constructively used prediction to say: If this . . . then *possibly* this. Through ambiguity, prediction suggested alternative possibilities. It called on people to see patterns emerging from present low levels of coherence. The prophets urged men to prepare, to avert disaster. So their prophecies were not fixed and foreordained; they

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addressed their listeners as free and responsible individuals, as people who could design their future. The desire to teach, rather than merely to predict, moulded their prophecies. They were men of vision, "seers."

Their attention focused on the present evolving toward a future of multiple alternatives. They were critics of society, revolutionaries; often they were leaders. The prophet, as Max Weber adapted the term for our day, is concerned with critical appraisal of his society in light of what he believes to be his society's fundamental values, its "self." The Hebrew prophets did more than denounce corruption. The prophet Ezekiel, during the Babylonian exile, developed a vast program for the reconstruction of the state of Israel (Ch. 40-8). Though his program was never realized, its vision did much to preserve the spirit and unity of the community in exile. For the seer, prediction differed from its connotation in the domain of science: it might be precise or ambiguous; the important point was that it should influence the course of events constructively. The prophet recognized many creative ways to influence events: the artistic statement, the powerful idea, the model that envisions, the warning that motivates. He saw small deviations that might become triggers to major changes, unfocused patterns that might, through successive approximation, become coherent.

Plato speaks of the "prophetic madness' of the Pythia (the priestesses) out of which emerged insight. A famous (though possibly apocryphal) prediction of the oracle at the Delphi, recounted forty years later by Herodotus, illustrates the potential open-endedness of prediction, used not as a scientific but as a creative tool. During the Persian Wars, when worried Athenians asked the oracle for guidance, the oracle told them to trust "the wooden wall." Herodotus relates how everyone had a different idea of what this message meant. Old men thought the god meant to tell them the Acropolis, which was defended by a wooden wall, would be safe. Others believed Apollo referred to the "wooden wall" of the ships that should be made ready. Of the group that thought he referred to the ships, some thought they should sail away to a new land without fighting, while others (including Themistocles) thought they should wage a sea battle. This last is what they did, destroying Xerxes' huge fleet at Salamis in one of the great battles of history.

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The role of the oracle here was not to give a single answer, but to motivate a thought process from which a number of alternatives emerged. Ambiguity, contradiction, and conflict played important roles in that constructive process. "Wooden wall" could be the attribute of several constructs, palisade or ships. Depending upon the framework within which it was viewed, it had a variety of meanings. The prophetic challenge was to determine the appropriate framework (pattern) for its interpretation. The ambiguity (open-ended possibility) in the prediction was resolved through its interpretation.[7] So, often, successful "prediction" relied not on the assumption of static stability in the course of events, but rather on the dynamics of interpretation. It took the form that emergence takes in the creative process, relying on instability, on ambiguity, contradiction, and conflict. By taking a parallel form, it allowed the image of the future to emerge through a parallel process.[8]

To recognize future patterns in present conditions is a consummate challenge. Humanists, looking at history and biography for insight into the mind's invention process, must accept the predictive limitations of their method. Lewis Mumford appropriately pointed out that an objective observed in the third century A.D. might well have predicted, looking at the imperial public works program, an increase in the number of public baths, gladiatorial arenas, garrison towns, and aqueducts. In fact, within three centuries the frontier garrisons were withdrawn, the Roman baths were closed, and some great Roman buildings were being used either as Christian churches or as quarries for new structures. Can anyone, asks Mumford, recalling this historic transformation, insist that the rate of scientific and technological change must accelerate indefinitely or that technological civilization will absorb all the energies of life for its own narrow purposes, profit and power?[9]

UNCERTAINTY AND EMERGENCE

The fourth connotation further emphasizes prediction's active role: it not only interprets; it may also construct. Prediction is linked with emergence precisely because of the *paradox of prediction*: the uncertainty inherent in observation means that any prediction (which the observer attempts to verify) will influence the observation. So the *paradox of prediction* warns us: a theory may predict, but the

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experiment that would confirm or refute that prediction may also be influenced by the prediction itself. The expectation of total objectivity is unrealistic. While those who would like to believe in the universal applicability of the "scientific method" will perhaps consider this lack of objectivity a shortcoming, those ready to accept that understanding may come also through a "constructive" paradigm akin to the arts will not be discouraged. We are called upon to recognize that reflexivity, an anathema to science based upon linear progression, has a necessary role to play in the theoretical (as well as the practical) construction of future possibility.

The connection of this fourth connotation of prediction with invention is not coincidental; both are expressions of thought and share its characteristic emergence and reflexivity with evolutionary biology. The intrinsic unpredictability of invention, both in the individual and in the evolution of cultures, is clarified by Jacques Monod's distinction between "emergence" (of something wholly new) and "revelation" (of something that existed but had not before been perceived) in biology: For those who regard evolution as the majestic unfolding of a program woven into the fabric of the universe, "evolution is not really creation but uniquely the *revelation* of nature's hitherto unexpressed designs. Hence the tendency to see in embryonic development an emergence of the same kind as evolutionary emergence. According to modern theory, the idea of *revelation* applies to epigenetic development [of a single organism], but not of course to evolutionary emergence, which, owing precisely to the fact that it arises from the essentially unforseeable, is the creation of absolute newness."[10]

Monod's distinction between "revelation" and "emergence," while useful, is not so clear with respect to creative processes as he makes it with respect to biology. The concept of possibility is slippery at best. Prediction concerns itself with possibility. Whether pre-existent possibility is revealed or whether it emerges, possibility by definition always "exists" if it can be stated as a possibility. So while Monod's distinction is important for biology, we shall find that, in discussion of the invention process, it is generally blurred, since prediction does not serve as a reliable criterion for making the distinction.

Mathematician Jacques Hadamard would probably relate this division to his distinction between discovery (the "revelation" of something that had not before been perceived) and "invention" (the

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"emergence" of something new). Hadamard differentiates as follows between invention and discovery: "Discovery concerns a phenomenon, a law, a being which already existed but had not been perceived. Columbus discovered America: it existed before him; on the contrary, Franklin invented the lightning rod: before him there had never been any lightning rod."[11] So Hadamard might say that discovery is "revelation" while invention is "emergence" of something wholly new.

Invention and discovery possibly lie on two sides of a continuum, while great creative accomplishments in both the arts and sciences fall in between. A great work of art, while an invention of the artist, must tap into fundamental laws of structuring in human nature and the universe, which existed before and will exist after the artist has passed. Similarly, any great scientific "invention," including Franklin's lightning rod, taps into fundamental structures and principles that already exist. Both represent the revelation of a possibility that was always there. Both teach us something about ourselves and the world.

Once again both "reveal" possibility or, if you prefer, possibility "emerges" as a recognizable figure from the confused ground of unrealized possibility. The issue here then is not whether we are discussing revelation or emergence. (Let's beg the question of whether there exists anything wholly new or not, since this debate offers nothing useful to our thesis.)

The challenge of science is to explain or predict what has hitherto been unexplainable and unpredictable. The challenge of the arts is to work creatively with mystery and unpredictability. And the great challenge both the arts and sciences must jointly accept in their studies of the human mind is to bring these two domains of exploration together.

It may be useful to consider several games and an evolutionary metaphor in preparation for sketching the characteristics of an invention process based on the *paradox of prediction*. I shall use the game of Twenty Questions to distinguish between pre-existent revelation (the passive connotation of prediction) and emergence constructed through participation (the active connotation of prediction). I shall then use the game of chess to distinguish between the path-oriented notion of prediction, having its basis in a causal chain of inference and the emergent notion of prediction constructed

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through pattern completion by making inferential leaps. These inferential leaps could not have been predicted *a priori* because the state from which the leap was to be made had yet to be constructed. Finally, drawing upon the ideas discussed in connection with the games of Twenty Questions and chess, I shall outline the characteristics of an invention process that disagrees with the traditional goal-oriented paradigm for problem-solving and posits instead the notion of successive approximation, which is fundamental to evolutionary emergence.

THE GAME OF TWENTY QUESTIONS

The game of Twenty Questions is more complicated than the problem of the camper trying to find his matches, since it operates with both "no" (elimination) and "yes" (selection). The Respondent thinks of something—anything. In twenty questions or less, which must be phrased so they can be answered by "Yes" or "No," the Questioner tries to close in on that object, to identify what the Respondent has in mind. It may be a toy, a tree, a fictional character, a historical event. The three questions most players start with are, "Is it an animal? A vegetable? Or a mineral?" but those three would not help us find a historical event, for example. What is surprising to the new player is the rapidity with which, starting with infinite degrees of freedom (everything is possible), the Questioner, through systematic questioning, can eliminate categories and "ambush" the object. In this game a "no" answer is as useful as a "yes"; both serve equally as guides.

The game of Twenty Questions bears analogy to nature's creative process of biological evolution. A "yes" answer to a question says: "Continue that path of questioning." "No" says: "That's the wrong path; try another question." The birth of a new organism is a question posed by biological evolution to the environmental context. If it survives to reproduce, the environment has said, "Yes, that idea fits well enough to merit development in this context." If it dies before reproducing, the environment has said, "Let's not try that again. Ask me a different question."

The game models a digital search process that attempts to find its "object" by the most efficient path or line of questioning. Note one difference between the game and biological evolution. Twenty Ques-

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tions is digital; the answers will be absolute: "yes" or "no." Nature's answers in the evolutionary process are yet more complex. They are analog, since they may fall anywhere on the spectrum between "yes" and "no." Digital systems are self-contained and therefore precise and verifiable because their operations are discrete rather than continuous. Analog models, on the other hand, do not have this perfect accuracy, since they simulate ranges that are continuous. To the organism the environment does not simply say, "No, you will not survive to reproduce," or "Yes, you will reproduce." Some organisms may reproduce more or less than others. "Differential rate of reproduction" computes in subtle ways nature's evolutionary directions. In an analog process there is the possibility of an incremental error, and this correlates with the possibility for transitional change.

In our simplified analogy the Questioner is the creative problem-solver. The Respondent plays the role of the environment or context, which accepts or rejects each creative act (each question). Clearly the context that a creative problem addresses will determine the appropriate form for its resolution. The Questioner starts with unbounded ground, the "enormous space" of Heraclitean consciousness whose boundaries have yet to be located. The entire universe is his context, and, from that universe of possibility, he must pick out the one figure (object) of his search. He does not know his "object" in advance, so, initially, figure and ground are confounded. The challenge of the game is to separate figure from ground. Gradually that which was undifferentiated or the contextual ground of the problem is differentiated and separated as figure.

Like the camper searching for a box of matches in the dark, the Questioner in Twenty Questions hopes accidently to hit the right path, the right line of questioning. He does not have the answer when he begins the search, but he selects the categories in which he will attempt to hit on useful accidents; he is aware of the overall frame defined by the questions already asked and the answers already received.

The game of Twenty Questions brings out two important points implicit in the notion that *selection criteria* and accident have together produced the striking products of evolution and human creative ingenuity. One tends to assume that the number of questions in the game is arbitrary. But suppose there were fifteen questions in the game, or thirty?[12] Why *twenty* questions? If there were fifteen, the

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Questioner would have to make larger inferential leaps to find the solution in fewer questions. He would have to be luckier in his choices of questions. If there were thirty questions, there would be so much information that he would need far less luck to find "it." So our first point: implicit in the combination of *selection criteria* with accident is the noting of intuition, which links the two. The camper looking for his matches, the Questioner choosing his questions, the Scientist or Inventor following his hunch are "lucky" in part because of intuition. (And there are some who would say that nature's evolutionary process is also directed by more than mechanism—that the universe possesses something akin to "intuition." It is intuition that enables the scientist to make the inferential leaps that C.S. Peirce referred to as "abduction"; it is intuition that connects decisions (and *selection criteria*) with happy accidents; and it is intuition that guides the formulation of prediction, when prediction itself is an inferential leap.

Our second point implicit in the combination of *selection criteria* with accident may seem, by comparison with the first, quite mundane. Again it is evident when we ask, "Why twenty, rather than fifteen or thirty questions?" The first point, the linking role of intuition, concerned the size of the inferential leap. The second concerns the base from which the leap is made. A vast amount of information is generated by 2^{20}, enough that in jumps of a reasonable size the normal person with average intuition should be able to "make it" in twenty questions. Fifteen questions may not give the Questioner enough raw material (in this case, patterned information) with which to construct his hypothesis.

The process in the case of Twenty Questions is one not of creation or *emergence* but of *revelation* of the hidden object, analogous to pattern recognition in the creative process. Pattern *recognition* and *revelation* are important constituents of all invention, artistic and scientific discovery processes to the extent that they all reveal possibility. But emergence participates in these processes as well. The distinction between emergence and revelation for Monod is determined by predictability. If instead we assert that all emergence (while perhaps unpredictable) is *recognition* and *revelation* of pre-existent "possibility," we have obliterated the distinction. Where "possible" though, it is useful to be able to distinguish between that which is predictable and that which is not.

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The solution to the game of Twenty Questions is clearly the "revelation" of the object in the Respondent's mind. Was that revelation predictable? What the Questioner would have to discover in order to succeed was already programmed before he began questioning. It is in that sense that Monod refers to predictability—not whether it is possible to predict, but whether there is a pre-existent program or "right answer."

A POSSIBLE QUESTION, A QUESTION OF POSSIBILITY

The reason you cannot play Twenty Questions with nature and win is simply that nature does not have the answer. Nature never decides in advance what she will create; she is subject to a step-by-step process of invention that nobody can predict in advance. Similarly, the creative actor establishes systematic *selection criteria* by which he will interpret the responses to his possible questions. He then "plays out the game" according to those criteria, though he may decide to revise them based on what he learns in the process. He does not know the precise goal (end result) in advance.[13]

Suppose that our Respondent, like nature, had not thought of anything before the Questioner began to ask his series of questions. What then? He would have to answer each question by "yes" or "no." For the first question he could arbitrarily pick "yes" or "no." His answer to the second would only need to be consistent with the first. The requirement that each answer be consistent with all previous answers would dictate that the game must by successive approximation converge toward an object that neither the Questioner nor the Respondent could have *predicted* in advance. This process would be a representation of what Monod refers to as *emergence*. This object would be defined as necessary by the sequence of questions that led to it. We can see that the object of the Questioner's search would not be absolutely defined until the last question made it the necessary unique object of that path.[14] Not until it existed as the object could it be unquestionably predictable as such. But would the Questioner ever reach that final question, the question that would tell him he had arrived? If he had a limit of twenty questions, then the twentieth would be "it," if consistent with the previous nineteen *and* if the Respondent were generous enough to concede. But when there is no twenty question limit, the game, if

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played without any preformulated answer, will, like nature's evolutionary process and man's creative work, never end.[15] There will never be a final answer from which one cannot pose yet another question: there will always be *a possible question* and a question of possibility.

In the original version of Twenty Questions, the right answer existed regardless of which questions the Questioner chose to ask. That version of the game is analogous to passive prediction where an event will come to pass regardless of whether it is predicted or not. In this new version of the game the answer did not exist *a priori.* It was created by means of the questions asked. Each question, together with its response, becomes part of the data base from which new questions are constructed. This version is analogous to active prediction, since the Questioner, by her choice of questions, and the Respondent, by her selection of answers, together create the Word. It did not exist (and could not have been predicted) prior to its creation.

Many scientists attempted to reconcile the implications of the Uncertainty Principle with classical physics by asserting that the observations existed *a priori;* it was simply the process of measurement that disturbed them.[16] This would provide an analogy to the original game of Twenty Questions. And classical science would be only moderately disturbed by our inability to observe what we could theoretically predict. But the problem is deeper; it is not the old "revelation" game of Twenty Questions that we are playing, but the new "emergence" game. Those results did not pre-exist.

The *paradox of prediction* warned us: where discovery simply reveals pre-existent patterns of a closed system, prediction is possible. But in an open system, invention is an "emergence" game. Prediction of its results is impossible. But does that imply that no model of the process can be constructed? Not at all. What it implies is that objective detachment should not be expected. A model of the invention process must itself be "invented" by the method it seeks to describe. Circularity is unavoidable.

This discussion has focused on the distinction between revelation of a pre-existent solution and emergence (or invention) of a new solution by a successive construction process. In Twenty Questions the notion of a path of questioning (a sequence of choices and actions) is apparent. But equally important is the concept of the frame that evolves gradually from incoherence (any solution is possible), to

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coherence and focus (this solution is "it") through pattern recognition in the game. The causal chain of questions relates to the goal-oriented paradigm of problem-solving, to decision trees and to linear progression. The notion of gradual pattern completion relates to the evolutionary paradigm of emergence through successive approximation, which complements the action sequence. While both of these complementary aspects operate in the game of Twenty Questions, they are more easily observed and understood in the game of chess.

THE GAME OF CHESS

Like Twenty Questions, the game of chess is played one move at a time. While strategies may be laid out, every strategy is subject to revision as situations emerge that were not predicted.

The game of chess is analogous to invention in that its possibilities are open-ended and unpredictable. The form that checkmate will take cannot be predicted before the game begins, nor is it determined with the first move. But with each successive move it is more and more determined until finally, with the last move, checkmate (final state or frame of the game) is absolutely determined, completely defined. By applying his *selection criteria* (the rules of the game plus his personal approach to playing the game), the chess player lets the precise definition of his goal, checkmate, evolve through the course of the game. Similarly, a work of art is only finally defined when the last brushstroke is applied. As Piet Hein said, "The work of art solves a problem which we could formulate until it was solved."

However, this analogy is useful not only for its similarities to, but also for its differences from the larger creative process we discuss. What the chess analogy brings out relates to our discussion of why *twenty* questions. A process is predictable to the extent that its domain is circumscribed. So, though we cannot predict at the outset of the game which particular form checkmate will take, we can conceive alternative possible forms. This relative predictability exists because chess is a relatively circumscribed domain.

In artificial intelligence there has been a tendency to analyze and mimic rather than to synthesize and reconstruct. This was the shortcoming of the early approaches to designing chess-playing computer programs. The significant role of subsequent attempts of AI

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to design a chess-playing computer in helping us to understand the human mind is that, where before students of the human mind tried in various ways to analyze it (by scientific methods), the development of computer software has forced scientists to try to synthesize its activities, an attempt that demands conceptual, artistic skills. It furnishes one powerful example that the greatest leaps in understanding take place not through analysis alone, but when analysis is brought to bear on problems of creative synthesis. It also reinforces speculative, conceptual studies of human invention, which attempt to construct hypotheses by a process analogous to the process they attempt to explain.

Consider the role of the human programmer in designing a chess-playing program. Just as genetic endowment produces an organism that will then survive to reproduce or not, so the programmer designs the program in advance, after which the chess-playing computer is "on its own" to win or lose the game. Clearly the programmer cannot anticipate all the billions of possible combinations of moves that could come up in a game of chess. All he can do is teach the computer the rules of play and give it additional *selection criteria* so that, whatever configuration comes up, it can apply those criteria and decide. Determining what the necessary *selection criteria* are is the great challenge and the reason that, so far, the human chess champion still wins.[17]

It is estimated that a world champion human chess player can hold a maximum of 50,000 patterns in his head whereas the most sophisticated chess-playing computer programs, Belle and Blitz, can consider ten times that number. Yet, so far, the human chess champion can still beat the best chess computer program. This seeming contradiction poses a creative question: If the computer has this tremendous computational advantage, why does the human win?

Perhaps the way we think we think is not really how we think. The computer program, whose artificial intelligence was modelled on the way we thought we thought, must play chess differently from the human chess champions.

Designers of computer chess programs started with the assumption that superior ability *to predict* how alternative scenarios (paths) in the game would play out would give the computer tremendous advantage over the human player. They were surprised to discover that it did not. In fact, it only "confused" the computer; every move in the

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game changed the board, and the computer started all over again to try to predict all the new alternatives. Human pattern recognition and strategic patterning capabilities outwitted the computer.

Experts analyzing this difference between the way the computer and human play chess hypothesize that the human player perceives the total pattern of the game at any given moment in time as a *Gestalt* (a frame), almost the way we recognize a face or a familiar neighborhood. Face and pattern recognition are considered synthetic (right brain) activities, suggesting that both right and left brain functions must operate together to win the game. The perception of *Gestalt* is a perception of now.[18]

As the game evolves, the human chess champion *generates* his strategy in the present. He *recognizes* patterns evolving. The problem for him is one of "coherence," or total pattern recognition and development. He is working not only with his linear sequence of moves but also with the global pattern of the chessboard. He is not primarily predicting; he is actively constructing. He is not jumping ahead to conceive future goals; he is working with present emergent patterns.

The computer, on the other hand, despite its superior ability to race ahead and compute future implications of alternative move sequences or paths (analytical function), tends to get distracted by every little change in the context of the game and to fail to structure a consistent strategy. For the computer, the process is solely analytic; the perception of *Gestalt* is the province of the human. *Patterning* in the present, rather than *predicting* future alternatives, seems to be more important to winning the game. This is simultaneously a right and left brain activity, an activity that demands recognition of *coherence* in patterns emerging.

We are now ready to outline how the invention process relates to the *paradox of prediction* and to the two games we have just discussed.

SUCCESSIVE APPROXIMATION THROUGH PERCEIVING DIFFERENCES

A conventional problem-solving model would say that the problem-solver looks at the present unsatisfactory state, compares the present state with a goal state, which he has already clearly defined, perceives

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the *difference* between the present state (chaotic) and the goal state (clearly organized), and tries to reduce the difference. This is fairly straightforward. We tend to confuse this "match present state with goal state" problem-solving with invention (which involves the gradual emergence and definition of the goal state). We neglect to realize that the two processes are totally distinct. The creative process of hypothesis construction in science and of concept formation in the arts begins with the uncertainty of "not knowing." It asks questions and gradually, through a series of questions, ambushes its object. It cannot state its goal, until it has created it. The goal is the hypothesis or concept that the process seeks to create.

Minsky, referring to Charles Babbage's original use of the term in 1822, calls machines that mimic goal-directed behavior "Difference Engines," since they must contain a description of the goal state and be able to recognize the various *differences* between present state and goal state. The "Difference Engine" integrated by finding differences in data, differences between differences (and so on), and extrapolating. Difference-engines are conceptually related to the "General Problem Solvers" investigated by Newell, Shaw, and Simon in the late 1950s.[19] But recognition of differences certainly does not presuppose goals. Isn't recognition of differences merely necessary to apply *selection critera?* If so, then the "Difference Engine" could chug along without ever applying its skills to contrast present state with goal state—by merely applying them to contrast present state with next state in order to choose what to do now at this moment of decision-making.

The notion of *iteration* and *successive approximation* is then applied not to "reducing the difference between the present state and the goal state" but rather to "reducing the difference between present state and next state." By coherence-seeking (comparing the present unresolved state with a possible more resolved next state), the process successively approximates its goal. Goals (future, as yet not revealed) relate to objects, and to the problem of prediction. *Selection criteria* (present), on the other hand, relate to the process whose goal, in an open system, is inherently unpredictable.

Starting from a "confused" initial condition, through the alternation of accident with assimilation, pattern gradually reveals its "self." The inventor needs the so-called (goal-directed) "Difference Engine," not to perceive the difference between present state and "goal state,"

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in order to match the two, but to see the difference between present state and *possible* "next states" in order to apply his *selection criteria* to ask the next question. The next response will enable the engine to decide what to do next. So the Difference Engine chugs from frame to frame, from this state to the next in the problem-solving process. It is a local train that must stop at every station. At each station it frames another question, "Wherefrom? Whereto?" to arrive at its destination.[20] These also, not coincidentally, are the questions of free association as the mental stream of consciousness flows (or chugs) from one thought to the next.

Consider a game that is related to the game of Twenty Questions but far simpler. A child looking for an Easter egg hears his parents say "you're getting warmer" or "cooler," and he knows whether he is moving in the right or the wrong direction. The scientist, artist, or inventor has a much more subtle challenge to recognize reinforcing or inhibiting signals that tell him he is moving toward or away from a successful result. In fact his definition of "successful result" (i.e., his goal) may be evolving and gradually becoming clearer in the course of the process (i.e., nobody hid that Easter egg in advance).

The response ("you're getting warmer; keep going this way and you'll find the golden egg" or "you're off track, try a different tack") is the positive/negative feedback that guides the process. Based on that response, whether positive or negative, you decide whether to maintain or change your actions, and you also decide whether to maintain or change your *selection criteria.* So selection criteria are not static rules; the game is one in which the player can change his criteria as he observes the effects of every move.

CONSTRUCTION AND COHERENCE-SEEKING

Coherence is the ability to see the pattern of the chessboard as a whole (as a frame); it refers to the existence of a predictable underlying pattern or structure of elements. The term is most frequently used in studies of human or artificial intelligence pattern recognition. The perception of coherence enables us to fill out the details of an ill-defined concept so that the resolution can gradually emerge through the process. The ability to recognize "coherence" is synthetic, requiring the artist or scientist to perceive implied structure

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and "fill in the blanks"—to bring together. The complementary skill of the analyst is classification—to take apart.

Coherence is a fundamental concept that relates not only to visible, organizational and conceptual patterns but also to functional systems. Coherent systems are characterized as non-rigid, evolving structures. An institution, community, city, or ecosystem, if it has the flexibility to operate and adapt to change, is a coherent system. It is on the perception of coherence that "educated guesses" are based. Speculation is imagining connections that may not be verifiable, recognizing structure that is only partially suggested, perceiving the pattern implied by partial information and filling in what is missing.

Michel Foucault refers to the "law of coherence as a heuristic rule": the notion that where contradiction arises in the history of ideas a higher unity [a new frame] is sought to restore coherence.[21] This is the word that E.T. Owen uses to describe Oedipus' final revelation of his identity; "He is overwhelmed by a sudden flashing into complete and terrible coherence, of all the disjointed intimations of the past . . . ."[22] The final frame (fate) or goal of this process is only clear when the final clue is in. When the final move has been made, the form of checkmate is revealed. And the quarry is the King, Oedipus himself.

There is a tendency in describing the creative process of hypothesis construction or concept formation to want something for the process to refer back to (an innate structure) or forward to (a goal). But, without taking any position on this issue, suppose that there is no fixity to which structuration can refer (no innate structures and no goals). Such total relativity is intuitively abhorrent. But is it possible? This discussion suggests the notion of coherence-seeking. Since coherence is a characteristic, not a structure, this notion substitutes relativity for fixity and provides a basis for the hypothesis of "successive approximation," as the means by which invention moves forward. *Problem-solving can then proceed without a referent (an innate structure to refer back to or a goal to refer forward to) by referring iteratively to itself and comparing each present step with a possible next step which is recognized through coherence-seeking.*

The ability to identify and categorize depends upon the ability to generalize. If we generalize back far enough we arrive at the types of primitive structures that Kant, Chomsky, and others have referred to as innate. Reversing direction, the ability to construct and specify

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depends upon coherence-seeking. Generalization, which takes us back to innate, unspecified structures, and coherence-seeking,[23] which takes us forward to construct and differentiate new, specific structures, are part of the same continuum. Acknowledging that the invention process lies on this continuum, we have implied that there must be innate structures as well as a constructive process.

The coherence-seeking process completes the pattern that has only partially been specified. Generalization and specification lie on opposite sides of one continuum. So the hypothesis of innate structures ties in with the premise of a constructive process based on coherence-seeking in the following way. Imagine that continuum as a surface. On the left are generalized innate structures. On the right are specified particular structures (e.g., specific hypotheses and concepts). Moving from left to right, the process of construction is a process of focusing and specification, going from the general (lack of differentiation) to the specific. Inferential leaps are required to specify and fill in the pattern that specification implies. This is a coherence-seeking process, which is dependent upon the ability to reverse that process, i.e., to differentiate into categories and to generalize. Note that we have not stated that the transformation process is itself reversible (it is frequently not). Rather, an individual's *ability* to conceive and construct (i.e., to direct a transformative process) is dependent upon possession of the complementary ability, to generalize and analyze.

Coherence is the concept upon which the notion of *successive approximation through iteration and gradual recognition* relies. If we diagram the three related hypotheses of how concept formation takes place as three vertices of a triangle, we might label one vertex "innate structures" and the second vertex "goals." The third vertex would be labelled "coherence." One of these three *referents* is necessary to guide the process. The process may refer back to innate structures (Chomsky et al.) or forward to goals (Piaget et al.) or, as this argument suggests, it may, through coherence-seeking (in process), refer to its "self," from present state to next state, through gradual and successive approximation. All three explanations rely on a referent and on the ability to compare. My guess is that each has a partial explanatory role to play; the acceptance of one explanation as plausible certainly does not preclude accepting one or both of the others.

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Whether innate mental structures (e.g., a universal template for language) exist that are later filled in with specific content, or whether schema are constructed, the question remains of how this is accomplished. We address that question, suggesting the importance of the concept of *coherence* (a quality that *describes* both things and processes but is not a thing or process in itself).

THE CONCEPT OF EVOLUTION, THE EVOLUTION OF CONCEPTS

The evolution of the concept of "evolution" is itself an entertaining study of emergence based on coherence-seeking. The quasi-evolutionism of eighteenth-century thinkers laid the conceptual foundations for Darwin's insight. Naturalist Georges Buffon wondered if the ass and the horse might have been descended from a single ancestor. Mathematician Pierre-Louis Maupertius imagined in 1751 that species might multiply due to the fortuitous recombination of particles of elementary organisms. Philosopher Denis Diderot postulated in 1753 one primeval, prototypical animal. And Linneas by 1760 admitted that species could vary. Darwin recounts how "in October 1838, that is, fifteen months after I had begun my systematic inquiry, I happened to read for amusement Malthus on *Population*, and, being well prepared to appreciate the struggle for existence which everywhere goes on . . . , it at once struck me that under these circumstances favourable variations would tend to be preserved and unfavourable ones to be destroyed. The result of this would be the formation of new species."[24] So it was in thinking about the law of population (and the problem of overpopulation) and asking, "What processes act to control population explosion?" that Darwin made the connection and came up with the theory of transformability of species through natural selection. Darwin, in the first five editions of the *Origin of Species*, did not use the term "evolution"; his intention was instead to show that species are modified over time by natural selection. Even the expression "survival of the fittest," later so important in evolutionary theory, did not appear in the first edition of the *Origin of Species*. Rather Darwin spoke of "descent" and "natural selection." Thirteen years later Darwin was to refer to "the great principle of evolution."[25] In fact the principle of evolution was implied at the outset, but it took time for Darwin and others (notably

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Herbert Spencer) to *recognize* it clearly as the completion that the conceptual pattern suggested.

In Darwin's formulation of his principle of "survival of the fittest," the *selection criteria* are in the environment, not in the process. This is because his model judged organisms as "objects," ruling out the role of behavior (the organism's decision-making apparatus). This argument suggests that the criteria lie both in the individual's creative process (which must interpret and act on feedback from the environment) and in the environment.

The Duke of Argyll reports a conversation he had with Darwin in 1882, the last year of Darwin's life: "In the course of that conversation I said to Mr. Darwin, with reference to some of his own remarkable work on *The Fertilisation of Orchids* and upon *The Earthworms* and various other observations he made of the wonderful contrivances for certain purposes in nature—I said it was impossible to look at these without seeing that they were in effect an expression of mind. I shall never forget Mr. Darwin's answer. He looked at me very hard and said, 'Well, that often comes over me with overwhelming force; but at other times,' and he shook his head vaguely, 'it seems to go away.' " Etienne Gilson comments that Darwin must have seen that astonishing inventions in nature were "the effect and expression of an elementary form of thought, or of a force related to thought, but because the evidence gave no purchase to demonstration, he turned his concerns away from it."[26]

As we conclude by connecting invention (whether biological or human) with thought, there is an important distinction to be made between closed and open systems. It has two implications: First, cognitive scientists often argue that the cognitive process is the same whether you are reinventing the wheel (assuming that you have never seen a wheel before) or inventing something new. Second, many similarly argue that the process is the same whether the results are predictable or not. According to this argument, a sufficiently rich and complex system, such as number theory, will demand the same creative ingenuity to develop as a novel invention, even though its theorems are entirely predicted by its axioms. Both of these cognitive objections relate to the game of Twenty Questions. They assert that the Questioner's cognitive process will be the same, regardless of whether there is a pre-existent right answer or not. In relation to the simplified analogy of the game I cannot disagree.

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However, the problem is very subtle, and I believe it goes to the heart of questions in artificial intelligence. I think there is an important distinction between the invention process in a closed system (a problem for which an answer exists *a priori* may be viewed as a closed system) and in an open system where new inconsistent, and unpredicted information can be assimilated by the process. That distinction points to the core of my argument. In a closed system the rules cannot change. In an open system they may. The process of invention involves more than simply filling out implied pattern. It involves making (and breaking) the rules by which pattern is constructed and selected. So it is not only the unpredictability of events, but also the unpredictability of the inventor (the possibility that he may change the rules of his game) that characterizes invention and links it with the arts. We cannot deny the important role inconsistency and contradiction play in this process.

We have considered both passive and active connotations of prediction. The passive connotations were based on the misperception that the so-called "scientific method" is a totally controlled process. The active connotations were traditionally based in the prophetic (sometimes mad) insights of the arts, but recently find place in the equally "maddening" insights of science. The "scientific method" assumes that theories must reliably (and passively) *predict* something, but it cannot construct the theory that will predict how theories will be constructed. The prophetic arts assume that their statements will (actively) *predict* alternative possibilities that we must construct, but to the extent that they remain to be constructed, they have not been predicted; and to the extent that prediction actively influences that construction, it did not passively predict it.

Similarly, the *paradox of prediction* has two aspects. The first is that, though we tend to think prediction makes a statement about the future, it in fact is simply a representation of our present understanding. Through *recognition* of emerging patterns in the present, prediction expresses the evolution of our understanding; to the extent that it becomes fixed, it cannot evolve, and therefore will not predict.

The second related aspect of paradox lies in the possibility that prediction may not be passive; it may actively influence the realization of the possibility it predicts. So there is a double reflection. Prediction both reflects and creates understanding; and to the extent that it "reflects" the future, it may also play a part in creating it. In the

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prophetic tradition prediction may ambiguously suggest multiple possibilities; it evolves with its interpretation. And it may actively influence the outcome of the events it predicts. We have throughout this discussion implied a connection between the *paradox of prediction* and the process of invention. That connection is Thought (a process) and Understanding (its attempted result). Prediction, invention, and thought are all evolving constructs, chugging forward into the future, attempting on the way to create order with accident and inconsistency by recognizing *possible* emergent structures.

We have come full circle. We have recognized the blurriness of the distinction between the two notions of prediction, the traditional scientific notion of passive prediction pointing to precise (or precisely statistically probable) results, and the artistic notion of active prediction both influenced by and influencing the outcome of events. A contemporary scientist readily concedes that his hypothesis can influence how he gathers his data and that his theory may affect his experimental results. Uncertainty is therefore a governing principle in both domains; in quest of the future, science and the arts are more one culture than we might at first suppose.

Just as in the simplified microworld of chess, both analysis and synthesis (pattern recognition and creation) must collaborate to win the game, it seems that both the arts and sciences must collaborate together in any attempt to understand how the human mind constructs hypotheses or forms concepts.

Art and science have been contrasted: art associated with speculation, science with investigation. Nelson Goodman considered the notion of "art as inquiry," recognizing both as complementary aspects of a single process and the two complementary facets of our one culture. Many, notably Karl Popper, have recognized science as speculation. Prediction is *possible* if we are playing a game of Twenty Questions in which the Respondent knows the answer in advance. But in the uncertain game of possibility, the mind's most creative game, it is the posing of the questions that demands both the scientist's systematic and the artist's exploratory approaches. Both the scientist and the artist are like the camper searching for a box of matches with a flashlight in the dark—using what light they have to search for the light they do not yet have, and asking, "Where can it *possibly* be?" The answer cannot be predicted; it must emerge from the confused background of unrealized possibility.[27]

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ENDNOTES

[1]Nelson Goodman *Fact, Fiction, and Forecast* (Cambridge, MA: Harvard University Press, 1983), p. 59.

[2]The term "selection criteria" refers to all of the components (e.g., rules, values, contextual conditions) that determine how a particular entity makes decisions. It does not presuppose consciousness. Thus the environmental context has selection criteria to select which organisms will survive. But the organism also has criteria by which it will individually fight for survival.

[3]Stephen Toulmin, *Foresight and Understanding: An Enquiry into the Aims of Science* (New York: Harper and Row, 1963), p. 24.

[4]See Ernst Mayr's clarification of this important distinction in *The Growth of Biological Thought: Diversity, Evolution, and Inheritance* (Cambridge, MA: Belknap Division of Harvard University Press, 1982), pp. 37, 57, 490, 863, and *Evolution and the Diversity of Life: Selected Essays,* (Cambridge, MA: Belknap, 1976), pp. 366–9.

[5]John Haugeland, ed. *Mind Design* (Cambridge, MA: M.I.T. Press, 1982), pp. 127–8.

[6]See the *Collected Papers of Charles Sanders Peirce* vol. 5, ed. Charles Hartshorne and Paul Weiss (Cambridge, MA: Harvard University Press, 1934), pp. 106–7 and *Philosophical Writings of Peirce*, ed. Justus Buchler (New York: Dover, 1955), pp. 151–2.

[7]Whether ambiguity lies in the prediction itself, or in our interpretation, its predictive impact is the same.

[8]The intention here is not to assert that all prophetic prediction takes an ambiguous, open-ended form, but rather that prophetic prediction had a range of possible *constructive* forms, some of which were quite precise. For a study of the Delphic oracle's precision, see Joseph E. Fontenrose, *The Delphic Oracle: Its Responses and Operations with a Catalogue of Responses* (Berkeley: University of California Press, 1978). This author suspects Themistocles of manufacturing the portent of the wooden wall to promote his own strategy. (pp. 124–8).

[9]Lewis Mumford, *Interpretation and Forecasts:* 1922–1972 (New York: Harcourt, Brace, Jovanovich, 1973), p. 476.

[10]Jacques Monod, *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology* trans. Austryn Wainhouse (New York: Alfred A. Knopf, 1971), p. 116.

[11]Jacques Hadamard, *The Psychology of Invention in the Mathematical Field* (Princeton, NJ: Princeton University Press, 1945).

[12]I am indebted to Arthur Loeb for this provocative question.

[13]Nelson Goodman puts this well: "A rule is amended if it yields an inference we are unwilling to accept; an inference is rejected if it violates a rule we are unwilling to amend." See Nelson Goodman *Fact, Fiction, and Forecast* (Cambridge, MA: Harvard University Press, 1983), p. 64.

[14]I had already developed this argument when I discovered J.A. Wheeler's intriguing reference to the game to make a different but related point. One of the after-dinner party is sent out of the room, the others agree on a word, the one fated to be the questioner returns and starts his questions, posing one to each member of the group in turn. Then comes the plot. When you are out of the room, the group agrees not to agree on a word. Each successive question takes longer to answer, until finally you ask, "Is it a Cloud?" and someone says "Yes." Wheeler

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in this thought experiment with the game is making a comment not only generally about indeterminacy but also specifically about the fact that, while observations in physics may be consistent, they are not predetermined; the observer (experimenter) is a participant in the emergence of the result. See John Archibald Wheeler, "Law Without Law," in *Quantum Theory and Measurement*, ed. John Archibald Wheeler and Wojciech Hubert Zurek, Princeton Series in Physics (Princeton, NJ: Princeton University Press, 1983), pp. 200–1.

[15]Slobodkin raises a related point: Evolution is like a game in which the only payoff is to stay in the game. So the strategy is neither to maximize efficiency, nor to achieve a particular reward [goal] but rather to keep playing the game—to persist by maintaining flexibility above all else. See L.B. Slobodkin, "The Strategy of Evolution," *American Scientist* 52 (1964), pp. 342–57.

[16]See Ilya Prigogine and Isabelle Stengers, *Order Out of Chaos: Man's New Dialogue With Nature* (New York: Bantam Books, 1984), p. 224.

[17]We should not here undervalue the "talent" of chess-playing programs. They do not simply use brute-force computation. Their decision-making procedure includes valuation functions about what moves are likely to contribute to center control, power balance, king safety, and so forth. They are able to consider not only the range of moves open to them in a given situation but also the likely future actions of their opponent. Even preprogrammed with these strategies, there are far too many alternatives.

[18]William G. Chase and Herbert A. Simon in "The Mind's Eye in Chess" wrote: "our earlier work, in conjunction with the pioneering work of de Groot, has led us to conclude that the most important processes underlying chess mastery are these immediate visual-perceptual processes, rather than the subsequent logical-deductive thinking processes .... De Groot found that Masters and weaker players have a great deal in common in the gross structure of their thought processes; he was unable to discover any quantitative differences that might underlie chess skill .... [However, one qualitative difference was that] Masters were able to reconstruct a chess position almost perfectly after viewing it for only about five seconds .... When the pieces were placed randomly on the board, recall was equally poor for Masters and weaker players .... It appears that the Master perceives familiar or meaningful constellations [i.e. patterns] of pieces. See William G. Chase, ed., *Visual Information Processing: Proceedings, Eighth Symposium*, Carnegie Mellon University, 1972 (New York: Academic Press, 1973), pp. 215–7.

[19]See Allen Newell and Herbert A. Simon, *Human Problem-Solving* (Englewood Cliffs, NJ: Prentice Hall Inc., 1972), and Marvin Minsky, *A Society of Mind*, unpublished draft, November 1985, p. 215.

[20]Wherefrom? and Whereto? were the questions psychologist Alfred Adler thought were implied in Leonardo da Vinci's free association Wordlists, a technique that scholars suspect da Vinci used to fuel his invention process. See references to "The Codex Trivulzianus" in Raymond Stites, *The Sublimations of Leonardo* (Washington, DC: The Smithsonian Institution Press, 1970), pp. 148–184.

[21]Michel Foucault, *The Archeology of Knowledge*, trans. A.M. Sheridan Smith (New York: Pantheon Books, 1972), p. 149.

[22]E.T. Owen, "Drama in Sophocles' Oedipus Tyrannus" in *Twentieth Century Interpretations of Oedipus Rex: A Collection of Critical Essays*, ed. Michael J. O'Brien (Englewood Cliffs, NJ: Prentice-Hall Inc., 1968), p. 40.

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[23]Coherence-seeking may be linked to the phrase Jerome Bruner made famous, "going beyond the information given." He delineated several ways: using inference, using redundancy, recognizing sequential patterns, using formal methods and coding systems, transference. Psychologists Bruner and Potter conducted "Interference in Visual Recognition" studies in which subjects were presented blurred pictures of common objects that were gradually brought into focus. As might be expected, they found that the greater the initial blur of the image, the more delayed was its recognition and identification. (See Jerome S. Bruner, *Beyond the Information Given: Studies in the Psychology of Knowing*, ed. Jeremy M. Anglin (New York: W.W. Norton and Co., 1973), pp. 4, 220–1.)

[24]See *The Autobiography of Charles Darwin and Selected Letters*, ed. Francis Darwin (New York: Dover, 1958), pp. 42–3.

[25]*Origin of Species*, sixth edition (1872), Chapter XV: "Recapitulation and conclusion," pp. 240–1. For reference to changes in the various editions of *The Origin of Species*, see *The Origin of Species: A Variorum Text*, ed. Morse Beckham (Philadelphia: University of Pennsylvania Press, 1959).

[26]See Etienne Gilson, *From Aristotle to Darwin and Back Again*, trans. John Lyon (Notre Dame, IN: University of Notre Dame Press, 1984), pp. 87.

[27]I would like to acknowledge the helpful comments of three people who read this article in draft: Mary Louise Gill, Ernst Mayr, and Scott Weinstein. "The Paradox of Prediction" is excerpted from my forthcoming book, *The Daedalus Dilemma*.

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Alistair C. Crombie

Experimental Science and the Rational Artist in Early Modern Europe

THE ESSENTIAL TERM IS THE ITALIAN *VIRTÙ*, which Leon Battista Alberti used in the fifteenth century for "those excelling gifts which God gave to the soul of man, greatest and preeminent above all other earthly animals."[1] A man of *virtù* in Renaissance Italian, coming from the Latin *virtus* meaning power or capability, was a man with active intellectual power to command any situation, to do as he intended, like an architect producing a building according to his design; by contrast with someone at the mercy of *fortuna,* of chance or luck, of the accidents of fortuitous circumstance, unforeseen and hence out of control.

The conception of the man of *virtù,* the *virtuoso* aiming at reasoned and examined control alike of his own thoughts, intentions, and actions and also of his surroundings, points to the essence of the moral and intellectual commitments by which the Western scientific movement was generated. The conception of *virtù* embodied a program for relating man to the world as perceiver and knower and agent in the context of his integral moral, social, and cosmological existence. The program presupposed the stability of nature and mankind and of their relations; it entailed a commitment to an examined life of reasoned consistency in intellectual, practical, and moral life alike and it generated a common style in the mastery of self, or nature and of mankind alike by the rational anticipation of effects.

To understand that common style we must take a long view reaching back to the Greek philosophers, mathematicians, medical men, historians, and dramatists who provided the models equally for

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the medieval and early modern scientific movement, as for the contemporary visual, musical, and literary arts. It was surely no accident that the same culture produced sciences and arts based alike on stable expectations, whether physical or moral: a mathematically and causally structured science of nature, a morally structured drama, and painting and music each structured mathematically to make their aesthetic or dramatic effects. The *virtuoso* was then the rational artist in all things, designing his intentions first by antecedent analysis in the mind, before executing them through the hands, whether he was aiming at mathematical or experimental investigation, at artistic composition, at the cultivation of private or public good by habit guided by right reason, or as an expedient politician at calculating from the regularities of human experience the most effective form of machination. We could take the *virtuoso* in this sense as diagnostic of Western civilization, as distinct from other civilizations of comparable or greater age and magnitude.

Also diagnostic is a particularly rational form of being blinded by reason, which we could call the blind idiot syndrome. This refers to a computer programmed to make translations. It was asked to translate from English into Russian, and then back again into English, the phrase: "Out of sight, out of mind." The phrase came back from the Russian: "Blind idiot." Problems of this kind have arisen from perceptions that oversimplify or in other ways fail to comprehend what exists, in this case what existed in the English language. In every culture at any time men have experienced their world through the mediation of a particular vision of existence and of knowledge. This defines their cultural style. Failures of European vision to comprehend what existed, because it was unexpected, appeared in abundance in the intellectual and pictorial records of European expansion overseas, whether into various parts of Asia, or the Americas, or the South Pacific.[2] Failures of scientific comprehension have regularly accompanied the revelations of such new scientific instruments as the microscope and telescope.[3] The history of scientific thought is strewn with examples of even the most original scientific minds failing to comprehend or even to acknowledge certain phenomena, which could not exist within their powerful theoretical vision. Technical frontiers may leave phenomena out of sight; conceptual frontiers put them out of mind.

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The style common to the Western sciences and arts may be illustrated by a collage of examples, through which will become evident the pattern in which in a diversity of contexts *virtù* imposed structure eventually even upon *fortuna* itself.

Thus wrote Plato: an architect used technical theory, providing antecedent analysis and design, as a "directive science" (*Statesman* 260 A–B) to control the construction of a building by means of measurement and calculation. For "all arts and forms of thought and all sciences employ . . . number and calculation" (*Republic,* vii, 522 C). Any artist or craftsman in making something "has before his mind the form or idea" (x, 596 B) of what he was to make. This was his model, just as the divine maker modelled the world from the eternal forms (*Timaeus* 28A–30C, 46C–48D, 53B). Sometimes in our perceptions "we are satisifed with the judgement of our senses" (*Republic,* vii, 523B), but sometimes the senses alone could not resolve the apparent contradictions or illusions produced by nature or by art, as when apparent size varied with distance or when a straight stick partly in water looked bent, or in "many tricks of illusion, like scene-painting and conjuring. But such illusions can be dispelled by measuring, counting and weighing. We are no longer at the mercy of the senses; reason takes control" (x, 602C–3B). Art then lay across the boundary between true representation and deceit. On one side was "the making of likenesses, as in creating a copy that conforms to the proportions of the original in all three dimensions with every part properly coloured": this was fairly called a likeness *[eikon].* But when for example the true proportions of a large sculpture were distorted to make them appear correct when seen from below, this only "seems to be a likeness" but is in fact merely "a semblance *[phantasma]* " produced by art (*Sophist* 225D–6C). Visual art then was like sophistry, which imposed upon its listeners "by means of words that cheat the ear, exhibiting images *[eidola]* of all things in a shadow-play of discourse so as to make them believe that they are hearing the truth" (234C).

The sophistries of rhetoric were aimed not at truth but only at persuasion; but a master of persuasion might share common methods of argument with a true scientist seeking a different goal. Plato likened the methods of rhetoric to those of medicine. Each, in order to reach its goal, had to discover the true nature of its object. Rhetoric had to grasp the nature of the soul in order to see how it was

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persuasible; medicine had to grasp the nature of the body in order to see how it was healthy or curable: "In both cases you must analyze a nature . . . if you are to proceed scientifically, not merely by practice and routine, to impart health and strength to the body by prescribing remedies and diet, or by proper discourses and training to give to the soul the desired belief and virtue." At the end of his analysis the scientific rhetorician "will classify the types of discourse and the types of soul, and the various ways in which souls are affected, explaining the reasons in each case: suggesting the types of speech appropriate to each type of soul, and what kind of speech can be relied upon to create belief in one soul and disbelief in another, and why." For "a certain type of hearer will be easy to persuade, by a certain type of speech, to take such and such action, for such and such reason; while another type will be hard to persuade. All this the orator must fully grasp, and next he must watch it actually taking place in men's conduct." When the student of rhetoric, having grasped the theory, could place any individual person in this classification of characters, and could know how to seize the occasion for the appropriate tricks, "then and not till then he has well and truly achieved the art." There was "absolutely no need for the budding orator to concern himself with the truth about what is just or good conduct" or "who are just and good men. . . . In the law courts nobody cares about the truth in these matters, but only about persuasion, and that is concerned with what seems most likely" for the purpose. The would-be master of persuasion must then suppress or substitute facts according to need and say "goodbye to the truth forever." Then he will be "equipped with the art complete" (*Phaedrus* 269D–73A).

Plato delineated very clearly in this account the goal of rational power over its subject matter that was to define the whole Western rational tradition, whether in seeking to find the truth or to persuade to belief or action. He set out systematically for the first time in his various writings the historic fact that mastery of rational scientific understanding brought with it power to manipulate matter and mind alike. Physical engineering and social engineering had the same form, and persuasion of the scientific (as of the artistic) acceptability of whatever was proposed or done became as much part of the scientific tradition as demonstrative proof.

According to Aristotle, everything constituted by nature "has within itself a principle of motion and of stationariness" (*Physics*, ii.

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1, 192b 14–15). Art by contrast imposed an external principle of change, but "art imitates nature" and hence was part of natural science (ii. 2, 194a 22–23). For "if a house had been made by nature, it would have been made just as it is now by art; and if things made by nature were made also by art, they would be made in just the same way . . .; in general art partly imitates nature, and partly completes what nature cannot complete." Thus "if the ship-building art were in the wood, it would produce the same results by nature" (ii. 8, 199a 12–17, b28).

Art, entailing the ability to invent by rational deliberation and choice and to learn, distinguished man from other animals. Man alone "lives by art and reasonings." Hence man alone could progress. Aristotle distinguished "mere experience" of particular sensory perceptions from "connected experience" where memory of particulars led to knowledge of general regularities. In the latter sense "experience seems pretty much like science and art, but really science and art come to men through experience." For "knowledge and understanding belong rather to art than to mere experience, and artists are wiser than men of mere experience . . .; because the former know the cause, but the latter do not" (*Metaphysics,* i. 1, 980b25–981a28). Then "with things made the principle is in the maker; it is either reason or art or some faculty" (vi. 1, 1025b22–3), and "all makings proceed either from art or from a faculty or from thought . . .; from art proceed the things of which the form is in the soul of the artist" (vii. 7, 1032a25–b1). Thus, whether in the practical, productive, or theoretical arts and sciences, two things were essential: "One is the choice of the right end or aim, the other is the discovery of the actions that will bring it about. . . . In all the arts and sciences both the end and the means should be within our control" (*Politics,* vii. 13, 1331b 25–37). Likewise in his moral behaviour man alone could choose and initiate his actions, and could, through practice guided by right reason, cultivate skill in virtue or vice as in any other art. Hence "choice is either desiderative reason or ratiocinative desire, and such an origin of action is a man" (*Nicomachean Ethics,* vi. 2, 1139b4–5). For "art is identical with a state of capacity to make, involving a true course of reasoning. All art is concerned with coming into being, that is, with contriving or considering how something may come into being which is capable of either being or not being, and whose origin is in the maker and not in the thing made"; it was in nature not in art

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that things existed "by necessity" (vi. 4, 1140a 1–16). By art then, by practice guided by reason, men acquired skill to control every aspect of their lives, whether in making material artifacts, or in managing the plants and animals and their own bodies or their fellow men, or in cultivating moral virtue or vice.

The fulfillment of human intelligence in the arts and sciences was made possible by the fact that "of all animals man alone stands erect, in accordance with his godlike nature and essence" (*De partibus animalium,* iv. 10, 686a 27–29), for this raised up with his head the most exact senses of vision and hearing, and liberated his hands as an instrument for making both artificial things and other instruments. Thus by mind, eye, and hand man was the animal alone equipped for technical advance.

There was an analogy between the rational art of nature and the rational art of man: "Our wonder is excited first by phenomena which occur in accordance with nature but of which we do not know the cause, and secondly by those which are produced by art despite nature for the benefit of mankind. Nature often operates contrary to human expediency; . . . when therefore we have to do something contrary to nature, the difficulty of it perplexes us and we must call art to our aid." Then by "mechanical skill . . .: Mastered by nature, we overcome by art" (*Mechanica,* c. 1, 847a 10-b 16). One could say of anyone who had grasped the revolutions of the heavens that "his soul is like that of whoever fashioned them in the heavens. For when Archimedes fastened on to a [metal] sphere the movements of the moon, the sun, and the five planets, he did the same as the god of Plato who built the world in the *Timaeus;* he made one revolution of the sphere control several movements utterly unlike in slowness and speed. Now, if in this world this cannot be done without a god, neither could Archimedes have been able to imitate those same movements upon a sphere without divine genius" (Cicero, *Tusculanae quaestiones,* i. 25. 61–3).

To investigate all the diverse subject matters of art and science upon which Aristotle imposed a similar rational form, he employed a likewise similar method of argument by analysis and synthesis. Thus he applied to politics as to physics "the method that has hitherto guided us. As in other departments of science, so in politics, the compound should always be resolved into the simple elements or least parts of the whole" (*Politics,* i. 1, 1252a 19–24). As with

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physical phenomena, so with the state and human society, the complex whole must first be analyzed into its elementary constituents, so that it could be reconstructed from those elements and so scientifically understood (*Physics,* i. 1, 184a9-b1).

Apart from the *Timaeus,* Plato's main works became known to the Latin West only with Marsilio Ficino's Latin translations made towards the end of the fifteenth century, followed by editions of the Greek. By contrast, practically all of Aristotle was known by the middle of the thirteenth century, mostly through the translations made during the previous hundred years. Hence philosophical conceptions of the relation of natural science to art, and of the structure of scientific argument, whether leading to scientific understanding or beyond that to artistic construction or engineering, were in early modern Europe at first predominantly Aristotelian. Later during the sixteenth century came the influence of Plato and with that of Greek mathematicians, especially Archimedes, in addition to Euclid, who had provided a model of scientific argument since the twelfth century.

The original insight by which the Greek mathematicians had discovered an abstract order behind the chaos of immediate experience was into a realm of simple relations, as in the mathematical sciences of astronomy, optics, mechanics, and acoustics, which they had developed most successfully. Their inquiry into the explanation of a phenomenon became a search for the simplest and fewest principles that would produce it. Then, when the principles were postulated, the phenomenon must follow. Thus they exploited the speculative power of geometry by imposing upon phenomena at once its deductive logical structure and an appropriate model delineating for each its form in space. Euclid had established the classical postulational style first by developing in the *Elements* a rational theory of geometrical space. From this he developed in the *Optics* a geometrical theory of what must be seen in specified situations, accepting his postulates, which took the eye as the point of origin of straight lines of vision. Similarly, in the *Sectio canonis,* he developed a theory of acoustical perception from the postulate that sounds were produced by motions standing in a numerical ratio to each other in which pitch was determined by frequency. Euclid and other Greek mathematicians aimed ideally to develop their research into the phenomena purely theoretically within their geometrical or arithmetical model. Later

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they came to realize, as did Ptolemy in his *Optics,* that in exploring complex phenomena postulation must be controlled by observation and experiment, in order to decide whether a possible theoretical model yielded the consequences found in the actual world. The style of scientific argument in optics came thus especially through Ptolemy, and likewise later through Alhazen, to be seen in the thirteenth-century West as one of experimentally controlled postulation.

This was to be the style of Renaissance art. It was already in the twelfth century envisaged as a program by Domingo Gondisalvo, following the tenth-century Arabic philosopher al-Fārābī: "The artist" he wrote "is the natural philosopher who, proceeding rationally from the causes of things to the effects, and from effects to causes, searches for principles." Thus for "what appears in vision," whether true or illusory, optics "assigns the causes by which these things are brought about, and this by necessary demonstrations." Likewise for music, and for engineering: "The science of engines is the science for contriving how one can make all those things . . . , of which the measures are expressed and demonstrated in mathematical theory, agree . . . in natural bodies. . . . The sciences of engines therefore teach the ways of contriving and finding out how natural bodies may be fitted together by some artifice according to number, so that the use we are looking for may come from them."[4] Again, Robert Grosseteste wrote in the thirteenth century: "All causes of natural efforts have to be given by means of lines, angles and figures, for otherwise it is impossible to have knowledge of the reason *[propter quid]* concerning them."[5] Hence the need for mathematics in all natural philosophical investigations. Likewise, according to the French architect Villard de Honnecourt a generation later, in building and making machines, in design and portraiture alike "the art of geometry commands and teaches"; and "in order to work easily," it must be kept in high regard by anyone "who wants to know how each must work."[6] Without going into the questions of precisely what these general programmatic utterances meant in particular practice, and of what mathematics meant in different contexts and periods, we may see in them a style of rational justification to be repeated again and again. No one was to argue more insistently than Roger Bacon for "the power of mathematics in the sciences and in the affairs and occupations of this world. . . . Of these sciences the gate

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and key is mathematics" (*Opus maius,* iv. 1. 1). That effective natural philosophy required also practical experimental art was eloquently stated by Bacon's contemporary Pierre de Maricourt in his letter of 1269, *De magnete.* For he wrote "while the investigator of this subject must understand nature . . . he must also diligently use his own hands." Then "he will be able in a short time to correct an error which he could not do in eternity by natural philosophy and mathematics alone, if he lacked care with his hands. For in hidden operations we greatly need manual industry, without which we can usually accomplish nothing perfectly. Yet there are many things subject to the rule of reason which we cannot investigate completely with the hand."[7]

Matching this rather with practical art than with natural philosophy in view, a contemporary asked of Alberti "in what class of learned men" to put him. He answered: "Among the natural scientists *[physici].* . . . Certainly . . . he was born only to investigate the secrets of nature. And what kind of mathematics does he not know? Geometer, arithmetician, astronomer, musician, he wrote marvellously better than anyone for many centuries on perspective. . . . He wrote on painting, he wrote on sculpture . . . and he not only wrote but also made with his own hands."[8] Alberti himself explained in 1435: "In writing about painting . . . we will, to make our discourse clearer, first take from mathematicians those things which seem relevant to the subject. When we have learned these, we will go on, to the best of our ability, to explain the art of painting from the basic principles of nature. . . . We will now go on to instruct the painter how he can represent with his hand what he has conceived with his mind."[9] Alberti exemplified in his account of the painter the active self-conscious man of *virtù,* the rational artist who made himself effective by means of knowledge, technique, and continual practice. Governing all his thinking was his perception of analogy within diversity. He searched in all his work for an economy of explanation and of practice reached by thinking out the general principle behind each subject, whether in perspective painting, in the anatomical variations of the human body as in *De sculptura,* in architecture as in *De re aedificatoria,* in surveying as in the *Descriptio urbis Romae* and *Ludi rerum mathematicarum,* in the relation of Italian vernacular to classical Latin as in the *Regule lingue florentine,* in the art of ciphering as in *De componendis cifris,* or in his theory of

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moral life. He looked everywhere also for the issue of theory in practice and thereby its confirmation by observation. Thus moral like scientific *virtù* was to be cultivated by reasoned analysis of personal and contemporary experience, and by discourse with other men both present and past who recorded the experience and reflections of mankind. The ultimate aim of man in his natural life on this Earth was to cultivate himself by reason, technique, and letters as a well-composed and controlled work of art. This was an Aristotelian humanist ideal viewed perhaps with skepticism by some contemporaries engaged more roughly with the real world, but its principle of reasoned control in an examined life had long been made part of traditional Christian moral theory. For Alberti it was the basis of both the personal and the social responsibility that all human activities and works entailed. Hence the necessity both for education and for that continual effort of practice in *virtù,* which alone could restrain the hazards of "unjust and malevolent *fortuna*" (*I libri della famiglia,* prologue, p. 3). God had endowed man with an inborn *virtù,* and this it was our duty to cultivate both for our own sakes and by our work "so that times past and those present will be of service to those that have not yet come" (*Profugiorum ab aerumna* i, pp. 122–3). "Our first and proper use is to exert the power of our soul towards *virtù,*" for: "To man alone among mortals is it given to investigate the causes of things, to examine how true are his thoughts and how good are his actions" (*De iciarhia* i, pp. 198, 212). At the same time he must live responsibly for the benefit of others, above all for "justice and truth" (ii, p. 286).[10]

All the practical arts proceeded then from a rational analysis of the subject matter and objectives of the art to their achievement in an appropriate representation or manipulation or use of the products of the analysis. Practical art like natural science became at once both highly intellectualized and precisely controlled. This was the intellectual bond uniting Alberti with his contemporaries, Nicolaus of Cusa, Paolo dal Pozzo Toscanelli, Georg Peurbach, and Piero della Francesca, in their common search for a quantified geometrical space and techniques for its measurement in astronomy and cartography, optics and painting alike; and again later uniting Leonardo da Vinci and Albrecht Dürer, and likewise the musicians Franchino Gaffurio, Lodovico Fogliano, and their successors in their search for an arithmetically quantified music that accommodated the requirements

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of the human ear. When Dürer wrote that "a good painter is inwardly full of figures," which pour forth "from the inner ideas of which Plato writes,"[11] he was presenting the aesthetic theory of an artist with both philosophical education and technical knowledge of practical mathematics. The program became a commonplace. Thus Giorgio Valla: "the artist reasons when he wants something for himself, fashions and forms it inwardly, and accordingly makes an image for himself of everything that is to be portrayed."[12] Marsilio Ficino: "What is a work of art? The mind of the artist in matter separate from it. What is a work of nature? The mind of nature in matter united with it. . . . And what is remarkable, human arts construct by themselves whatever nature herself constructs, as if we were not slaves of nature but rivals." But "not just anybody can discern by what principle and in what way the work of a clever artist, artistically constructed, is put together, but only he who has the same power of artistic genius *[artis ingenium]*. . . . And he who discerns on account of similarity of genius could certainly construct the same things when he had recognized them, provided materials were not lacking." Since therefore man had seen and measured the order of the heavens, "who will deny that he has a genius (so to speak) almost the same as that of the Creator of the heavens and that he could in a certain way make the heavens if he obtained the instruments and celestial matter; since he makes them now, though of other matter, yet very similar in arrangement."[13] Leonardo da Vinci: "Astronomy and the other sciences proceed by means of manual operations, but first they are mental as is painting, which is first in the mind of him who theorizes on it, but painting cannot achieve its perfection without manual operation."[14] But "although nature starts from the reason and finishes at experience, for us it is necessary to proceed the other way round, that is starting . . . from experience and with that to investigate the reason."[15] "There is no effect in nature without reason: understand the reason and you do not need experiment."[16] "Oh speculator on things, I do not praise you for knowing the things that nature through her order naturally brings about ordinarily by herself; but, I say, rejoice in knowing the end of those things which are designed by your own mind."[17]

Four ancient works that were to propel in this same direction conceptions developed in the sixteenth century of the relations between the arts and sciences were the Aristotelian *Mechanica,* Hero

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of Alexandria's *Automata,* Proclus's neoplatonic commentary on the first book of Euclid's *Elements,* and Vitruvius's *De architectura.* Thus Vitruvius on the architect: "His works are born from both construction and reasoning" (i. 1. 1). Men learned to devise the machines *[machinae]* and instruments *[organi]* necessary for improving the material arts by imitating the "devised nature *[natura machinata]*" (x. 1, 4) exemplified in the celestial revolutions. An exegesis of these terms given in the philological commentary on the earliest Italian translation (in 1521) made the essential point: "*Machinatio* . . . may be derived from I cunningly contrive, . . . I deliberate, I think out, . . . stratagem, . . . whence undertaking, thinking, machine and . . . mechanic or mechanical operator."[18] "*Machina.* . . . Mechanics . . . is commendable whether for its basic imitative resemblance to the divine work of the construction of the world, or for the great and memorable usefulness reached. . . . And that furthermore . . . has been put into practice through burning desire to produce in sensible works with their own hands that which they have thought out with the mind."[19] Daniele Barbaro in the principal sixteenth-century Italian commentary on Vitruvius wrote of Michelangelo that "the artist works first in the intellect and conceives in the mind, and then signs the external matter with the internal habit."[20] But "the intellect of man is imperfect and not equal to the divine intellect, and matter so to speak is deaf, and the hand does not respond to the intention of art." Hence "the architect must think very well and, in order to make more certain of the success of the works, will proceed first with the design and the model . . .; and . . . he will imitate nature, which does not do anything against its maker. Yet he will not search for impossible things, either as to the matter or as to the form, which neither he nor others can accomplish."[21]

The limits of the possible in nature were brought into sharp focus by these rational artists whose essential purpose was to succeed in the practical execution of their projects. Thus Giuseppe Ceredi, engineer and scholar of Greek mathematics, insisted that "I am accustomed to practice both with the mind and with works"; for "I remembered, as was well said by Aristotle and Galen, that no science or art aimed at action can be perfectly possessed by anyone who may know its precepts but does not then confirm them with a variety of experiments *[esperienze]* many times and finally succeeding." There was a powerful precedent for "putting into execution so many beautiful

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mathematical and physical reasons, seeing that nature herself, as if become mechanical *[quasi divenuta mecanica]* in the construction of the world and of all forms of things, seems to be striving designedly to produce every hour more ingenious instruments *[artificiosi organi]*." Theory had been opened up for Ceredi by his being sold some manuscripts of Hero of Alexandria, Archimedes, Pappus, and other Greek mathematicians from the collection made at Milan by Giorgio Valla. Putting theory into practice, he offered as a method of antecedent analysis in any undertaking the construction of "small and large models *[modelli]*, adding, changing, and removing many things according to whether the condition of the material, or the coming together of many far and near causes, or the variety of means, or the degree of the proportions, or the force of motions, or many other impediments that one can encounter, required it." Thus he could conveniently bring together the "numerous observations" that had to be made and kept "in the mind in order to achieve some new and important effect." For in order "to bring them properly together and to direct them firmly to the prescribed work," errors had to be recognized "from experience and so corrected by reason that at last one comes to the perfection of art and to the stable production of the effect that is expected."[22] Again Guidobaldo del Monte pointed out that "art with wonderful skill overcomes nature through nature herself, by so arranging things as nature herself would do if she decided that such effects should be produced by herself."[23]

Art then could not cheat nature, but by discovering, obeying, and manipulating natural laws, with increasing quantification and measurement, art was seen to deprive nature of her mysteries and to achieve its mastery by reasoned foresight, whether in the representation of a visual scene, the design and control of a machine, the composition of music, the navigation of a ship across the ocean, or optimistically the diagnosis, prognosis, and control of a disease or even of the affairs of state. Galileo was defining the identity at once of nature and of natural science when he commented on engineers who "would apply their engines to works of their own nature impossible: in the success of which both they themselves have been deceiv'd, and others also defrauded of the hopes they had conceiv'd upon their promeses . . .; as if, with their engines they could cosen nature" and her "inviolable laws." For "this is according to the necessary constitution of nature. . . . Nay if it were otherwise, it were

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not only absurd, but impossible. . . . And . . . all wonder ceases in us of that effect which goes not a poynt out of the bounds of nature's constitution."[24] Galileo's last pupil and first biographer Vincenzo Viviani wrote significantly that for him "the book of nature" was "always open to those who enjoyed reading and studying it with the eyes of the intellect." He said that the letters in which it was written were the propositions, figures, and conclusions of geometry, by means of which alone was it possible to penetrate any of the infinite mysteries of nature. If the intellect did the reading, the "main doors" through which it entered in order to do so were "observations and experiments, which could be opened by the noblest and most inquisitive intellects by means of the keys of the senses." Viviani drew attention to Galileo's training both in music (through his father Vincenzo Galilei), showing in the First Day of the *Discorsi e dimostrazioni matematiche intorno a due nuove scienze* (1638) "a marvellous understanding of the theory of music," and in perspective drawing (at the Florentine Accademia del Disegno), delighting in painting, sculpture, architecture, "and all the arts subordinate to design."[25]

Living from Michelangelo's death to Newton's birth, Galileo marks the transition between two great European intellectual movements each in its own way dominated by mathematical rationality: the transition from the world of the rational constructive artist to that of the rational experimental scientist. The common element in these intellectual movements and the channel of their mutual influence seems to have been their common form of argument: their common use of postulation controlled by practical experience and experiment. That is what emerges from our collage of examples stretching from Plato to Galileo. It extended much more widely than those examples, to the whole conduct of life by the man of *virtù*, who knew how to proceed with rational intent in the control at once of argument and of a variety of materials and activities. This was the style also of the right reason of Aristotelian ethics, exemplified by the moral and political philosophy of Thomas More and more ambiguously of Machiavelli. But we should not confuse Machiavelli's moral intentions with his analysis of the technique that would enable the political *virtuoso* to succeed as a blackguard if he so chose. In the same style the rational artist achieved a common mastery of his materials, whether in the mechanical, plastic, visual, or musical arts or in the

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experimental sciences, by an antecedent analysis providing a rational anticipation of effects. Thus Galileo wrote of his law of falling bodies: "I argue *ex suppositione,* imagining a motion"[26] that might be possible, following the example of Archimedes. This then led him to the experiments by which he decided whether that possible motion was realized in the actual world.

The experimental philosopher as rational artist might make his antecedent analysis by means of theory alone, quantified as the subject matter allowed, or by modelling a theory with an artifact analytically imitating and extending the natural original. Galileo was behaving in a way just like his exact contemporary Shakespeare, when he offered an analysis of human character in his imaginary world which we recognize at once as true of our real experience.

Scientist and artist alike were creating possible worlds that would in some way explain the real world of experience. They were both in different ways creating theoretical models, and it is through the model in its various forms that the interpenetration of art and science can be seen at its most telling. Painters from the time of Alberti used scientific optics to carry out an analysis of visual clues, by means of which they could construct a painting by simulating those clues: that is as a perceptual model imitating the natural clues in true perspective. To make then they had first to know. At the same time their perceptual models affected the way people looked at the natural world and what they saw in it. Conversely, in explaining the technique of perspective painting, they also provided models for the physiological operation of the eye. Kepler solved the problem of the formation of the retinal image by first isolating the geometrical optics of the eye from the questions of causation and perception, inherited within the package of ancient and medieval theories of vision, which inhibited a purely geometrical physical analysis. He treated the eye as a *camera obscura* containing a lens.[27] To know then we might say that physiologists, at least when they tackled some problems, had first to learn how to make. The invasion of science by art through the method of hypothetical modelling went very deep during the seventeenth century. For some natural philosophers indeed art seemed to have taken over the epistemology of natural science altogether.

Thus wrote Marin Mersenne: "One is constrained to acknowledge that man is not capable of knowing the reason for anything other than that which he can make, nor other sciences than those of which

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he makes the principles himself, as one can demonstrate in considering mathematics."[28] Again in examining physical things "we must not be surprised if we cannot find the true reasons for the way they act or are acted upon, because we know the true reasons only for things that we can make with the hand or with the mind; and because, of all the things that God has made, we cannot make a single one, whatever subtlety or effort we bring to it; besides which God could have made them in some other way."[29]

The experimental natural philosophers and the rational artists were creating possible worlds for themselves and each other and for a wider public in more ways than one. The analysis of visual clues carried out for the purposes of perspective painting showed what must be seen when these were present. At the same time it generated expectations in those familiar with it of what they should be seeing to produce a given set of clues received. Thus Galileo with training in perspective and *chiaroscuro* saw and drew through his telescope in 1609 mountains and valleys on the moon, just as they could be seen and touched on an indented stone ball; Thomas Harriot with no such training saw through a comparable instrument in the same year only strange spots.[30] Likewise the exact measurement and true scaling required by linear perspective completely transformed the communication of information in the sciences and technical arts through pictorial illustrations. The immediate effects were apparent in the views and in the sixteenth-century plans drawn of cities, in cartography, and in the depiction of the external and internal structures of animals, plants, minerals, and of machines. Depiction became an instrument of scientific research. It seems that the engineers Mariano di Jacopo, called Taccola, and Francesco di Giorgio Martini, to name only two, designed their machinery by inventive drawing before construction;[31] and that Descartes expected to find in the animal body a kind of mechanism analogous to mechanisms made familiar in printed illustrations.[32]

Matching perspective painting within the mathematical and experimental arts and sciences, which established a unique style of thought and action in early modern Europe, was music. The science of music, like that of perspective, was concerned primarily with the identification and quantitative analysis of clues to sensations: the acoustical quantities expressible in numbers which stimulated the diversities of auditory perception. It was Mersenne who finally

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developed the science of music as a systematic exploration of a whole subject matter. Again he aimed to show how through scientific analysis to achieve rational control: of musical perception and its effects on the emotions, of composition through a calculus of permutations and combinations of notes, and of information communicated through sound leading to a theory of language. "Music is a part of mathematics" he opened his first musical essay, the *Traité de l'harmonie universelle* (1627), "and consequently a science that shows the causes, effects and properties of sounds, tunes, concerts, and of everything that belongs to them." The science of music depended then on arithmetic and geometry "but also on physics from which it borrows knowledge of sound and of its causes, which are the movements, the air, and the other bodies that produce sound."[33] He developed his science of music as a program of systematic measurement of the acoustical quantities effecting hearing, combined with an analysis on one side of the physics of sound producing these external quantities, and on the other of the internal processes mediating sensation and its effects on the soul. As in painting, all attempts to establish a scientifically rational control over musical composition foundered on the pecularities of auditory as of visual perception in providing aesthetic pleasure through art. The judgements of the ear could often differ from the expectations of mathematical theory. The science of music, developed during the sixteenth and seventeenth centuries, clarified this important question, notably in exploring the relation of aesthetic pleasure to mathematical proportions and physical motions in consonance and dissonance, and the effects of cultural habits, familiarity, the expectations of the ear, and their changes. Aesthetic judgements thus differed essentially from those of science, even though there might be general agreement among knowledgeable persons within any particular period or culture.[34] Mersenne recognized this, but he exemplifies once more the rational artist in his aim to stabilize all auditory experience by scientific theory covering sounds and sensations, their aesthetic effects, and their functions in human and animal communication.

Through his systematic conception and practice of acoustical "expériences bien reglées et bien faites"[35] Mersenne became a major architect of the modern experimental argument. He based his experimental analysis on the logic of agreement, difference, and concomitant variations with an explicit use of experimental controls. Thus to

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investigate the acoustical phenomena of vibrating strings (fundamental in musical theory since Pythagoras) he stretched two strings on a monochord. One was the control. In the other he kept all the relevant quantities (length, tension, specific weight) constant except one, and adjusted the remaining variable quantity in this string until it sounded in unison with, and hence vibrated with the same frequency as, the control. In this way he completed the work of Giambattista Benedetti, Vincenzo Galilei, Isaac Beeckman, and others in establishing the relations of frequency (hence pitch) to these quantities. Beyond that, by measuring the actual frequencies (as distinct from their ratios) producing different pitches and intervals he demonstrated experimentally for the first time that the musical intervals were determined by frequencies of vibrations of the air, whatever their source. He went on to explore, distinguish, and measure further acoustical quantities: the upper and lower limits of audible frequency and pitch and their variation in different individuals, the speed and loudness of sound, and the relation of loudness to distance, the phenomena of resonance, consonance, dissonance, temperament, harmonics, and so on.[36]

Mersenne's style as a rational artist is well illustrated by two examples concerning in two different ways the control of information. By treating the ratios of the frequency of strings to the quantities determining it as in effect an acoustical function, he showed how a "deaf man could put them at any consonance he wished," without hearing anything, by adjusting these quantities in accordance with the "general rules" embodied in this function. For the benefit of the deaf he drew up a table showing the quantities that would produce the different notes of an octave.[37] Thus he could generalize experimental information beyond its receipt by a particular sense. Even more generally, his conception of human and animal language as both biological and social phenomena, his attempt to account for the reception and communication of information in men and animals firmly by empirical and experimental investigations, and his rethinking of the physiological coordination of behavior, led him to look for the common elements in all human languages and beyond these in all forms of communication whether by human beings, animals, or machines. In this analysis he saw a possible means of inventing a new universal language for communication among all mankind. This would redeem the scandal of Babel, and would reunite mankind

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whose common understanding of meaning through a common reason had been disintegrated by the diversification of languages following the diverse and separate historical experiences of different peoples. Again Mersenne's model was music. Basing his linguistic experiments on a calculus of permutations and combinations of a given set of elements that he had already developed for musical composition, he proposed to devise a system of notations that could be expressed symbolically in music.[38] Increasing European awareness of the diversity of the cultures of the world and of the relativity of human values and expectations directed attention in the seventeenth century to the diversity of the perceptual worlds inhabited by different peoples, and also by animals.[39] Deaf mutes likewise raised the question of the mental world of persons deprived of a sense. Following his analysis of music and the voice he proposed a method (already used in Spain by Pedro Ponce of Léon) of teaching the deaf to speak by showing them how to form the tongue and lips in appropriate positions and then associating these with written words and with the things they signified.[40] Thus the science of music, including in it all the phenomena of sound, could restore personal dignity and bring about the unity of mankind within the rational and stable *harmonie universelle* that God had chosen to exhibit, both in the structure of his physical creation and in the information about it that men were able to discover and communicate.

Antecedent theoretical analysis could direct the experimental argument in different ways. Theoretical expectations could open inquiry in certain directions and close it in others. Within a general and conventional agreement that trial by experiment was the ultimate test, a diversity of theories of what existed or could exist in nature, both in general and in particular, created expectations of what could or what could not be found by experimental inquiry. The boundaries of rationality either of nature or of scientific knowledge, however clearly defined by some leading scientific *virtuosi* in the seventeenth century, were never accepted within all the diverse intellectual and social contexts concerned. Thus experiment and mathematics could have different meanings within inquiries directed by different preconceptions of what was discoverable in nature, and their results could give different satisfactions according to whether what was supposed to be discoverable could be interpreted as having been discovered. Kepler, for example, looked with neoplatonic vision for harmony in

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nature expressed in simple mathematical proportions supported by sound metaphysical reasons, and he insisted throughout that the proportions postulated must agree with observation. His quarrel with Robert Fludd, who shared something of the same vision, was that Fludd would not agree to acceptable experimental criteria for believing rather in one kind of world than in another, so that when Fludd cited measurements made with his weather glass (a kind of thermometer), they could not agree even on what was being measured. Between the absolutely different mental worlds they inhabited, the one as a scientific rational artist and the other as a Hermetic magician, there could be evidently no communication.[41] Theory well supported by experimental argument could also blind even the most rational natural philosophers to unexpected experimental novelties. William Gilbert's theoretical expectations obstructed for a generation recognition that the declination of the magnetic needle from true north varied in the course of time, even though the evidence was available.[42] William Harvey refused to accept that the lacteal vessels and thoracic duct discovered by Gasparo Aselli and the *receptaculum chyli* discovered by Jean Pequet had any function in the transport of nourishment from the intestines to the body: he objected theoretically on the grounds that these vessels were not found in all animals whereas the necessity for such transport was universal, that the mesenteric veins were sufficient, and that "nature never does anything thoughtlessly."[43]

Harvey was well aware of the analogy between the rational artist, who formed in his mind a conception of what he would represent in his painting and how he would do so, and the rational experimental scientist who proceeded likewise by an antecedent theoretical and quantitative analysis of his subject matter. For "art itself is nothing but the reason of work, implanted in the artists minde. And in the same way by which we gaine in art, by the very same we attain any kinde of science or knowledge whatever: for as art is a habit whose object is something to be done, so science is a habit, whose object is something to be known; and as the former proceedeth from the imitation of exemplars; so this latter, from the knowledge of things naturall. The source of both is from sense and experience" (with the Aristotelian meanings respectively of particular sensory perceptions and connected experience of their regularities), "since it is impossible that art should rightly be purchased by the one, or science by the

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other, without a direction from ideas."[44] Experimental scientist and rational artist were then both alike exemplary men of *virtù,* achieving their objectives by a similar intellectual behavior, mastering their subject matters by an analytical anticipation of effects, and committed to an examined life of reasoned consistency in all things. In this context the rapid extension in the seventeenth century of scientific experience of the exploration of nature generated its own critical response. This was twofold, scientific and epistemological. The response in scientific method was a dramatic increase in the power, precision, and range of techniques of logical, mathematical, and instrumental analysis. The response in epistemology was a stricter and stricter examination of what scientific investigation could be accepted as having established. Within the ambience of a certain general philosophical skepticism, the contrast between the acknowledged successes of the mathematical and technical sciences and arts in solving specific and clearly defined problems, and the disputed claims of metaphysicians to true and certain knowledge of the whole essence of existence, led to the conclusion that scientific art alone could yield the only certainly true science of nature available to us. Scientific thinking has nearly always been guided or stimulated by ideas or beliefs coming from outside the strict boundaries of scientific demonstration. Through the seventeenth century, scientific experience itself brought about a recognition, within an increasingly professional scientific community, that positive reasons must be required for accepting such beliefs as valid or relevant within a scientific argument. The scientific movement, propelled by a deliberate combination of a theoretical search for common forms of explanation with a practical demand for accurately reproducible results, came then to base the acceptability of scientific explanations on a criterion of art: the range of experimental confirmation on an open frontier, capable of yielding not certainty but only probability to a degree increasing with its range.

The triumphal march of rational *virtù* towards control of scientific ideas of all kinds received at this point a check, indicated by Mersenne, from experienced scientific skepticism supported by theology: the doctrine of the omnipotent Creator which reduced the world from the human point of view to contingent regularities of fact.[45] What then about the realm of *fortuna* that *virtù* aimed to master, the realm of untidy accidents and unfathomable motivations,

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of contingent expectation and uncertain choice? One aspect of that realm was mastered by reason through the calculus of probability, developed first in the context of commercial insurance and partnerships from the fourteenth century in Italy, and reduced by Pascal and Christiaan Huygens to an exactly calculated expectation at any point of time. Thus as Pascal wrote "what was rebellious to experience has not escaped the dominion of reason. Indeed we have reduced it by geometry with so much security to an exact art, that it participates in its certainty and now boldly progresses. And so, joining mathematical demonstrations with the uncertainty of chance, and reconciling what seemed contraries, taking its name from both, it justly arrogates to itself this stupendous title: the geometry of chance *[aleae geometria]*."[46] Scientifically that may be said to have removed some aspects of the game of life from the long accepted realm of irrational fortune and personal luck into that of impersonal calculation.

But what about those other seemingly irrational aspects of human motivation that have always been recurrently part of our culture: the temptations of magic or demonology for example, or the apparently deliberate cultivation of evil or the desire to destroy or deconstruct from whatever motive but for no evidently positive end? Out of sight in ages of reason, the dramatic irrationalism of our time has sensitized our minds to its counterparts in earlier periods. It has reverberated through our century like a Wagnerian opera: too loud, too long. How should a historian of *virtù* treat it? Certainly not like a blind idiot. Rather he can use his rational judgement as a kind of comparative historical anthropologist, getting to the viewpoint of its motivations, commitments, and expectations, in the past as in the present, in the minds of its historians as of their subjects, however irrelevant it may seem to the history of the problems solved by science or art.

ENDNOTES

[1]Leon Battista Alberti, *I libri della famiglia,* ed. Cecil Grayson (*Opere volgari,* vol. 1, Bari, Italy: Laterza, 1960), p. 133; cf. for full documentation of this paper with bibliography Alistair C. Crombie, *Styles of Scientific Thinking in the European Tradition* (London: Duckworth and Co., 1987); also "Science and the Arts in the Renaissance: The Search for Truth and Certainty, Old and New," *History of Science* 18 (1980), pp. 233–46, and in *Science and the Arts in the Renaissance,* ed. John W. Shirley and F. David Hoeniger (Washington, DC: The Folger

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Shakespeare Library, 1985), pp. 15–26, "Philosophical Presuppositions and Shifting Interpretations of Galileo" in *Theory Change, Ancient Axiomatics and Galileo's Methodology: Proceedings of the 1978 Pisa Conference on the History and Philosophy of Science,* vol. 1, ed. Jaakko Hintikka, David Gruender, and Evandro F. Agazzi (Dordrecht, Holland: D. Reidel, 1981), pp. 271–286, "Historical Commitments of European Science," *Annali dell'Istituto e Museo di Storia della Scienza di Firenze,* 7 (2) (1982), pp. 29–51: these and other papers are included in A.C. Crombie, *Science, Optics and Music in Medieval and Early Modern Thought* (London: Hambledon Press, 1986). A shorter version of this present paper was given at Williams College, MA, while Visiting Bernhard Professor, at the conference organized there by Professor Samuel Y. Edgerton, Jr. in October 1984 on "Art and Science in Related Revolutions." For the relations between the arts and the sciences in this period there are Rafaello Caverni, *Storia del metodo sperimentale in Italia,* 6 vol. (Florence: 1891–1900); Leonardo Olshiki, *Geschichte der neusprachlichen wissenschaftlichen Literatur,* vol. 1 (Heidelberg: 1919), vol. 2 (Leipzig: 1922), vol. 3 (Halle an der Salle: 1927); Hedley Rhys, ed., *Seventeenth Century Science and the Arts* (Princeton, NJ: Princeton University Press, 1961); Erwin Panofsky, "Artist, Scientist, Genius: Notes on the 'Renaissance-Dämmerung' " in *The Renaissance: Six Essays* by Wallace K. Ferguson et al. (New York: Harper Torchbooks, 1962), pp. 121–82; William P.D. Wightman, *Science in a Renaissance Society* (London: 1972); and Shirley and Hoeniger, eds., *Science and the Arts in the Renaissance;* and for most of the persons named the *Dictionary of Scientific Biography,* ed. Charles C. Gillispie, 16 vol. (New York: Charles Scribner and Sons, 1970–80).

[2]Cf. Bernard Smith, *European Vision and the South Pacific: A Study in the History of Art and Ideas* (Oxford: Oxford University Press, 1960); Garbard M. Stafford, *Voyage into Substance: Art, Science, Nature, and the Illustrated Travel Account, 1760–1840* (Cambridge, MA: MIT Press, 1984).

[3]Cf. Gerard L'E Turner, "The Microscope as a Technical Frontier in Science" in *Proceedings on the Royal Microscopical Society* 2 (1967), pp. 175–197; Bernard Cohen, "The Influence of Theoretical Perspective on the Interpretation of Sense Data: Tycho Brahe and the New Star of 1572, and Galileo and the Mountains on the Moon," *Annali dell'Istituto e Museo di Storia della Scienza di Firenze* 5 (1) (1980), pp. 3–13; Ian Hacking, "Do We See Through a Microscope?" *Pacific Philosophical Quarterly* 62 (1981), pp. 305–22; Samuel Y. Edgerton Jr., "Galileo, Florentine 'disegno,' and the 'Strange Spottedness' of the Moon," *Art Journal* (Fall 1984), pp. 225–32, and "The Renaissance Development of Scientific Illustration" in *Science and the Arts,* ed. Shirley and Hoeniger, pp. 168–97.

[4]Dominicus Gundissalinus, *De divisione philosophae,* ed. L. Baur (*Beiträge zur Geschichte der Philosophie des Mittelalters,* 4 (2–3) Münster: 1903), pp. 10, 27, 112, 122; cf. Alpharabius, *De ortu scientiarum,* ed. C. Baeumker (ibid., 19 (3) Münster: 1916).

[5]Robert Grosseteste, *De lineis, angulis et figuris* in *Die philosophischen Werke,* ed. L. Baur *(Beiträge zur Geschichte der Philosophie des Mittelalters,* 9 Münster: 1912), p. 60; cf, A.C. Crombie, *Robert Grosseteste and the Origins of Experimental Science 1100–1700* (Oxford: Oxford University Press, 1953, 1971).

[6]Villard de Honnecourt, *Kritische Gesamtausgabe des Bauhüttenbuches ms. fr. 19093 der Pariser Nationalbibliothek* ed. H. R. Handloser (Vienna: 1935), folios 1^{v}, 18^{v}, 19^{v}.

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[7]Petrus Peregrinus Maricurtensis, *De magnete* book 1, ch. 2, ed. G. Hellman (*Rara magnetica; Neudrücke von Schriften und Karten über Meteorologie und Erdmagnetismus* 10 Berlin: 1898).

[8]Cristoforo Landino, *Commento . . . spora la Comedia di Danthe Algheri* (Florence: 1491), folio iv^{r}.

[9]Alberti, *De pictura* book 1, sections 1 and 24, ed. Grayson in *On Painting and on Sculpture* (London: Phaedon Press, 1972), p. 36, 58.

[10]Alberti, *Opere volgari,* ed. Grayson, vol. 1 (1960) and vol. 2 (1966).

[11]E. Panofsky, *The Life and Art of Albrecht Dürer,* 4th ed. (Princeton, NJ: Princeton University Press, 1955), p. 280.

[12]Giorgius Valla, *De expetendius et fugiendis rebus opus,* book 1, ch. 3, (Venetiis: 1501).

[13]Marsilius Ficinus, *Theologica Platonica,* book 4, ch. 1, book 13, ch. 3 (*Opera,* Basilae: 1576), pp. 123, 295–7.

[14]Leonardo da Vinci, *Treatise on Painting, Codex Urbinas Latinus 1270,* book 1, chs. 19, 35 trans. A.P. McMahon (Princeton, NJ: Princeton University Press, 1956): a posthumous compilation.

[15]Leonardo da Vinci, *Les manuscrits . . . de la Bibliothèque de l'Institut,* Codex E., ed. Charles Ravaisson-Mollien, folio 55^{r} (Paris: Institut de France, 1888).

[16]Leonardo da Vinci, *Il Codico Atlantico nella Biblioteca Ambrosiana di Milano,* transcribed by G. Piumati, folio 147^{v} (Milan: 1894–1904).

[17]Leonardo da Vinci, *Les manuscrits* Codex G., ed. Ravaisson-Mollien, folio 47^{r} (Paris: 1890).

[18]Marcus Lucius Vitruvius Pollio, *De architectura libri dece, traducti de latino in vulgare, affigurati, commentati,* book 1, ch. 3 (Como: 1521) folio 18: begun by Cesare Cesariano and completed by Benedetto Giovio and Bono Mauro; see Paolo Galluzzi, "A proposito di un errore dei traduttori di Vitruvio nel '500,' " *Annali dell'Istituto e Museo di Storia della Scienza di Firenze* 1 (2) (1976), pp. 78–80.

[19]Vitruvius, ibid., book 10, ch. 1 commentary folio 162^{v}.

[20]See the preface of Daniele Barbaro, *I dieci libri dell' Architettura di M. Vitruvio, tradutti e commentati* (Venice: 1556), p. 9.

[21]Ibid., 1 (3), p. 26.

[22]Giuseppe Ceredi, *Tre discorsi sopra il modo d'alzar acque da' luoghi bassi,* book 1 (Parma: 1567).

[23]Guidobaldus e Marchio Montis, *In duos Archimidis Aequeponderantium libros paraphrasis scholiis illustrata,* Preface (Pesauri: 1588), p. 2.

[24]Galileo Galilei, *Le mecaniche,* national edition, ed. Antonio Favaro (*Le Opere* 2 Florence: G. Barbèra, 1968), p. 155, trans. Robert Payne (1636): transcribed from the British Museum MS Harley 6796, f. 317^{r}, by Adriano Carugo.

[25]Vicenzo Viviani, "Racconto istorica della vita di Galileo" (1654; *Le Opere* 19), pp. 625, 627; cf. A.C. Crombie, "The Primary Properties and Secondary Qualities in Galileo Galilei's Natural Philosophy" in *Saggi su Galilei* (Florence: G. Barbèra, preprint 1969), *Styles of Scientific Thinking,* Ch. 3, section 4; A. Carugo and Crombie, "The Jesuits and Galileo's Ideas of Science and of Nature," *Annali dell'Istituto e Museo di Storia della Scienza di Firenze* 8 (2) (1983), pp. 1–68, republished in A.C. Crombie, *Historical Studies in Scientific Thinking* (London: Hambledon Press, 1987); Crombie and Carugo, *Galileo's Natural Philosophy* (forthcoming).

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[26]Galileo to Pierre de Carcavy, June 5, 1637, *Le Opere* 17, pp. 90–1; cf. to Giovanni Battista Baliani, January 7, 1639, ibid., 18, pp. 11–13.

[27]A.C. Crombie, "The Mechanistic Hypothesis and the Scientific Study of Vision," *Proceedings of the Royal Microscopical Society* 2 (1967), pp. 3–112, republished in *Science, Optics and Music.*

[28]Marin Mersenne, *Les questions théologiques, physiques, morales, et mathématiques,* question 22 (Paris: 1634) 111; cf. Robert Lenoble, *Marin Mersenne, ou la naissance du mécanisme* (Paris: J. Vrin, 1943); Crombie, "Mathematics, Music and Medical Science," *Actes du XII^e Congrès International d'Histoire des Sciences, Paris 1968* (Paris: A. Blanchard, 1971), pp. 295–310.

[29]Marin Mersenne, *Harmonie universelle,* vol. 2, "Nouvelles observations physiques et mathématiques" (Paris: 1637), p. 8.

[30]Edgerton, "Galileo, Florentine 'disegno,' and the 'Strange Spottedness' of the Moon," pp. 225–32.

[31]Edgerton, "The Renaissance Development of Scientific Illustration," pp. 168–97; also Joan Gadol, *Leon Battista Alberti: Universal Man of the Early Renaissance* (Chicago, IL: Chicago University Press, 1969).

[32]Eg. Salomon de Caus, *Les raisons des forces mouvantes avec diverses machines tant utiles que plaisantes, aus quelles sont adoints plusieurs desseigns de grottes et fontaines* (Frankfurt, Germany: 1615); cf, Willem van Hoorn, *As Images Unwind: Ancient and Modern Theories of Visual Perception* (Amsterdam: University of Amsterdam Press, 1972).

[33]Mersenne, *Traité de l'harmonie universelle,* book 1, theorem 1 (Paris: 1627), pp. 2, 9; cf. for music Claude V. Palisca, "Empiricism and Musical Thought" in *Seventeenth Century Science,* ed. Rhys, pp. 91–137, "The Science of Sound and Musical Practice" in *Science and the Arts,* ed. Shirley and Hoeniger, pp. 59–73; D. Perkin Walker, *Studies in Musical Science in the Renaissance* (London: Warburg Institute, 1978); Crombie, "Mathematics, Music and Medical Science," pp. 295–310, "Marin Mersenne (1588–1648) and the Seventeenth-Century Problem of Scientific Acceptability," *Physics* 17 (1975), pp. 186–204, *Styles of Scientific Thinking,* ch. 3, section 4, *Marin Mersenne and the Science of Music* (forthcoming); Jamie C. Kassler, "Music as a Model in Early Science," *History of Science* 20 (1982), pp. 103–39; H. Floris Cohen, *Quantifying Music: The Science of Music in the First Stage of the Scientific Revolution, 1580–1650* (Dordrecht: D. Reidel, 1984).

[34]Cf. Palisca, "Scientific Empiricism and Musical Thought"; Walker, *Studies in Musical Science in the Renaissance;* Cohen, *Quantifying Music;* Crombie, *Styles of Scientific Thinking.*

[35]Mersenne, *Harmonie universelle* vol. 1, "Traitez de la nature des sons, et des mouvemens de toutes sortes de corps," Book 3, proposition v (Paris: 1636), p. 167.

[36]See for these investigations Crombie, "Mathematics, Music and Medical Science," and "Mersenne, Marin (1588–1648)" in the *Dictionary of Scientific Biography* 9 (1974), pp. 316–22.

[37]Mersenne, *Harmonie universelle* vol. 2, "Traitez des instrumens," vol. 3, prop. vii (1637), pp. 123–6, cf. prop. xvii, pp. 140–6, vol. 1, props. xvi–xx, pp. 42–52.

[38]Ibid., vol. 1, "Traitez de la voix . . . ," book 1, especially props. xii, xlvii-l, pp. 12–13, 65–77, "Traitez . . . des sons . . . ," book 1, props. xxii, xxiv, pp. 39–41, 43, vol. 2, "De l'utilité de l'harmonie," prop. ix, also *La verité des sciences,* book 3, ch. 10 (Paris: 1625), pp. 548, 544–80, *Les questions théologiques, physiques,*

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morales, et mathématiques question 34 (Paris: 1634), pp. 158–65 (expurgated edition); cf. Lenoble, *Marin Mersenne, ou la naissance du mécanisme;* Crombie, "Mathematics, Music and Medical Science," "Marin Mersenne (1588–1648) and the Seventeenth-Century of Scientific Acceptability," and *Styles of Scientific Thinking,* ch. 3, section 4, ch. 7, section 1; Mersenne, *Les questions théologiques, physiques, morales, et mathématiques,* and *Traité de l'harmonie universelle; Arno Borst, Der Turmbau von Babel: Geschichte der Meinung über Ursprung und Vielfalt der Sprachen und Völker,* 4 vol. (Stuttgart: 1957–63); Hans Aarsleff, *From Locke to Saussure: Essays on the Study of Language and Intellectual History* (Minneapolis, MN: 1982); Mary Slaughter, *Universal Languages and Scientific Taxonomy in the Seventeenth Century* (Cambridge, England: Cambridge University Press, 1982).

[39]Mersenne, *Les préludes de l'harmonie universelle,* question 6 (Paris: 1634), pp. 150–7, *Questions harmoniques,* questions 1–3 (Paris: 1634), *Harmonie universelle,* "Traitez de la voix . . . ," book 1 prop. lii, pp. 79–81, cf. props. v–xiv, xxxviii–xli. pp. 7–15, 47–55; Thomas Willis, *De anima brutorem* (Oxford: 1672).

[40]Mersenne, "Traitez de la voix . . . ," book 1 props. x–xi, li, pp. 11–12, 77–9; cf. David Wright, *Deafness* (London: Allen Lane, 1969); Crombie, "Mathematics, Music and Medical Science"; Harlan Lane, *When the Mind Hears: A History of the Deaf* (New York: Random House, 1984), *The Deaf Experience* (Cambridge, MA: Harvard University Press, 1984).

[41]Cf. Wolfgang Pauli, "The Influence of Archetypal Ideas on the Scientific Theories of Kepler" in Carl G. Jung and Pauli, *The Interpretation of Nature and the Psyche* (London: Routledge and Kegan Paul, 1955).

[42]Cf. Eva G.R. Taylor, *The Mathematical Practitioners of Tudor and Stuart England* (Cambridge, England: Cambridge University Press, 1955).

[43]William Harvey to Robert Morrison, April 28, 1652 in *The Circulation of the Blood,* trans. Kenneth J. Franklin (Oxford: Oxford University Press, 1957), p. 86.

[44]Harvey, *Exercitationes de generatione animalium,* Preface (London, 1651), translated as *Anatomical Exercitations Concerning the Generation of Living Animals* (London: 1653).

[45]Cf. A.C. Crombie, "Infinite Power and the Laws of Nature: A Medieval Speculation" in *L'infinito nella scienza* (Rome: Istituto della Enciclopedia Italiana, 1986), republished in Crombie, *Historical Studies in Scientific Thinking.*

[46]Blaise Pascal, "Adresse à l'Académie Parisienne" (1656), ed. Louis Lafuma (*Oeuvres complètes,* Paris: Editions du Seuil, 1963), pp. 102–3; cf. A.C. Crombie, "Contingent Expectation and Uncertain Choice: Historical Contexts of Arguments from Probabilities" in *The Rational Arts of Living,* ed. A.C. Crombie and Nancy G. Siraisi (Northampton, MA: *Smith College Studies in History,* 1986), republished in Crombie, *Historical Studies in Scientific Thinking;* cf. *Styles of Scientific Thinking,* ch. 6, section 2.

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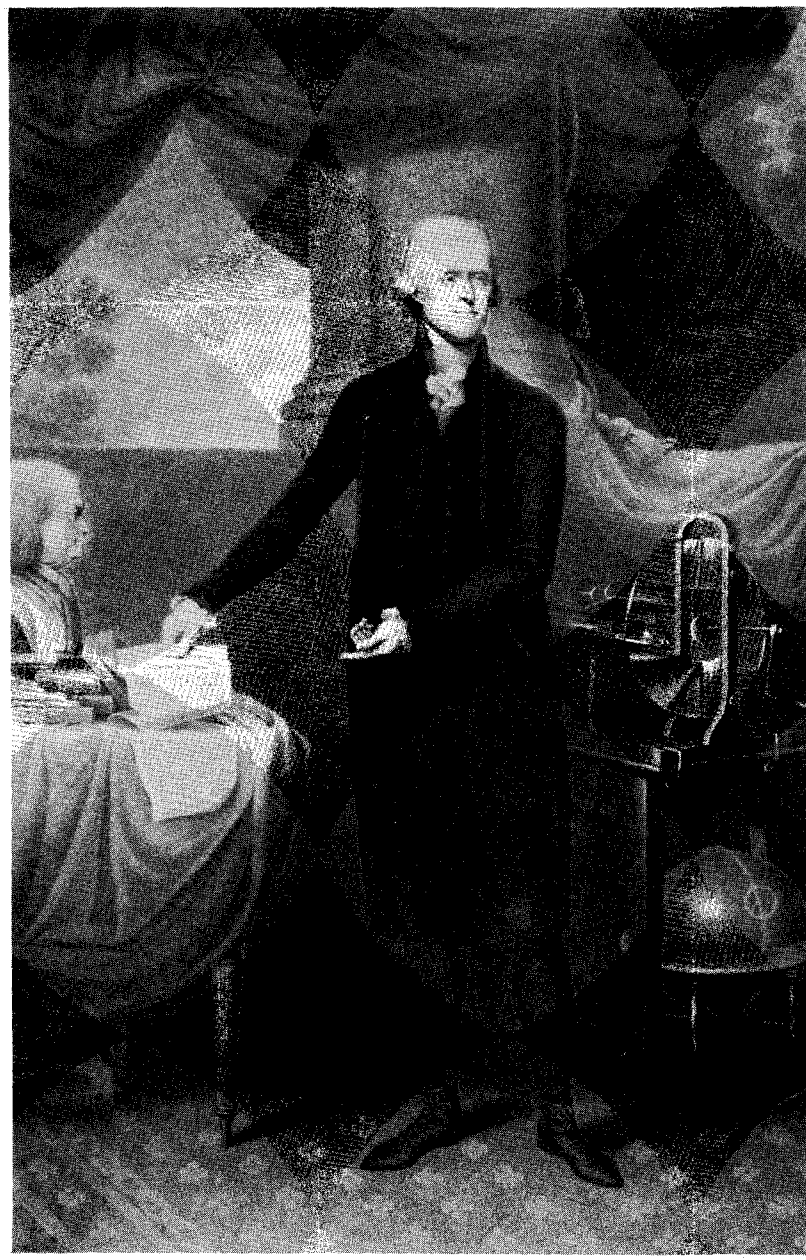

PRESIDENT THOMAS JEFFERSON; from an engraving by Cornelius Thiebout, 1801.
Courtesy of the Library of Congress.

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Gerald Holton

The Advancement of Science, and Its Burdens[1]

As the first of the Jefferson Lecturers to have been brought up in science, one of my themes must be the nature of scientific understanding; and as the first speaker in the series to have come to this country in search of a haven of liberty, my other main theme necessarily concerns the conditions that strengthen or threaten democracy—the more so as the award directs the occasion be "in the service of the general public interest," bringing to bear the speaker's experiences "upon aspects of contemporary culture and matters of broad public concern."

Thomas Jefferson himself, I believe, would have had no difficulty discerning the connection between the two themes, between the power of science and the condition of society. He saw a double purpose for the pursuit of science: the advancement both of knowledge and of "the freedom and happiness of man." From the many examples that would serve as practical illustrations of Jefferson's twin goals, let me select his protracted study of the design for the humble plough.

In 1788, while acting as Minister in France but still a farmer at heart, he noted the unwieldy plough used there. Little seems to have escaped Jefferson, certainly not any inefficiency that might also impede the development of his own young country. His curiosity went to work. He wrote: "The awkward figure of their Mould board

[1]Somewhat expanded version of the tenth annual Jefferson Lecture, given in two parts (Washington, DC, and Boston, May 1981). This is a chapter in the forthcoming book, G. Holton, *The Advancement of Science, and Its Burdens* (Cambridge University Press, Fall 1986).

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leads one to consider what should be its form." He sketched how the wedge-shaped mouldboard of the plough should raise the soil so that it would topple properly by its own weight.

Three years later he described the progress he had made: "I have imagined and executed a Mould board which may be mathematically demonstrated to be perfect, as far as perfection depends on mathematical principles, and one great circumstance in its favour is that it may be made by the most bungling carpenter and cannot possibly vary a hair's breadth in its form but by gross negligence."

He made a model of it. To improve it further, in 1798, Jefferson, then vice-president of the United States, took from his shelf Emerson's *Treatise on Fluxions,* his old college book on the calculus, and re-derived the shape of the mouldboard and ploughshare that would offer least resistance to the soil. In 1805, while President, Jefferson made yet another model, writing to a friend, "it took half a day . . . which I could not spare till very lately." He submitted it to the American Philosophical Society, and he made plans to have the ploughshare cast in iron for wide distribution. He was awarded a gold medal for it by the Society of Agriculture, and published a scientific paper on the design. By May 1808, Jefferson had read in the Memoirs of the French Agricultural Society of the Seine District that an improved plough existed in France. He arranged to have one sent to him, despite the embargo his administration was enforcing on France. By October of that year he had received a French dynamometer and made experiments on the resistance of the plough to show that his was better than the best in France. Last but not least, he advocated the horizontal or contour method of ploughing, "instead of straight furrows." This ecologically sound method, he wrote, "has really saved this hilly country. It was running off into the valleys with every rain, but by this process we now scarcely lose an ounce of soil."

Jefferson is indeed an exemplar of the whole linked sequence of responsible research in science and technology: a concern, at the initial stage, for a technical solution to a socially significant problem; the innovation using, where necessary, the application of mathematics; the experimental tests; the disclosure by publication; the further development with a view to mass production; and, most significantly, the demand that the invention be used to benefit both the people and the land. His was a coherent course of thought and action.

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Jefferson persuaded Congress to back the Lewis and Clark expedition as a venture with commercial potential; but to the Spanish authorities, through whose territory they were to pass, he described it as a purely scientific mission. That was shrewd, but also right. The mixture of both motivations was correct. Jefferson regarded the expedition as a scientific survey of the place to which the nation's destiny was likely to lead. This dual-purpose style of research—basic scientific study that had no certain payoff in the short term but was targeted at an area of national importance—deserves a name. We would do justice to call it the "Jeffersonian Research Program."

* * *

My intention is not to paint Jefferson as a scientist. On the contrary, my main point is that he and others of his period, while unique in history as political thinkers, were typical of their time in that they considered it as natural to share in the current scientific world picture as in the classics of literature, philosophy, and statecraft.

If we turn our attention to this century's intellectuals, we find a situation very different from the comfortable incorporation of science into the world view that characterized the most prominent of the eighteenth-century models. At some point in the course of history, the intellectual pattern of our civilization changed. I must develop this point now, not because of a nostalgic longing for a return to eighteenth-century euphoric hopes (voiced in Voltaire's projection that "reason and industry will progress more and more, that the useful arts will be improved, that all the evils that have afflicted man . . . will gradually disappear"); not because a current mutual incomprehension impairs discourse in the Common Rooms of some English colleges; but for a far more important reason—because we are witnessing a disjunction in the political and social life of the nation that curtails a main legacy of Jefferson's America, namely, our power of self-government.

My first witness is appropriately the writer, literary critic, and historian, Lionel Trilling, who in 1972 gave the first Jefferson Lecture, entitled "Mind in the Modern World." He began by reminding his audience of the loss of confidence in the power of mind, a confidence that had been characteristic of Jefferson's time.

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The old credo was that "if mind were cleared of its inherited illusions and prejudices, . . . what has long been accepted as the inevitable rule of harsh necessity, might be overthrown, and mankind will achieve a felicity which was its immemorial dream and its clear evolutionary destiny." That was once true. But Trilling thought the title of the last book by H.G. Wells was a more appropriate summary of our present condition: *Mind at the End of its Tether.* Trilling pointed to two causes for the weakening of what had been a master belief for Jefferson and his time. One reason was our diminishing awareness of the past, what he called our "disaffection from history." But if the loss of history in our time has been, in a sense, self-inflicted and voluntary, such was not the case for the second, equally disorienting disability. For, Trilling continued, "the old humanistic faith conceived science, together with mathematics, to be almost as readily accessible to understanding and interest as literature and history." Jefferson, of course, could take that for granted; but this faith has been lost. Science, in our day, Trilling explained, "lies beyond the intellectual grasp of most men . . . . Its operative conceptions are alien to the mass of educated persons. They generate no cosmic speculations, they do not engage emotion or challenge imagination. Our poets are indifferent to them."

Having despaired of the hope Wordsworth expressed in the 1802/1805 preface to the *Lyrical Ballads,* that the remotest discoveries of the scientists "will be as proper objects of the Poet's art as any upon which can be employed" if these things "shall be familiar to us," Trilling added a paragraph that captures the anguish of the modern intellectual, to whom nothing is more devastating than the irredeemable remoteness of a whole continent of fundamental knowledge:

> This exclusion of most of us from the mode of thought which is habitually said to be the characteristic achievement of the modern age is bound to be experienced as a wound given to our intellectual self-esteem. About this humiliation, we all agree to be silent; but can we doubt that it has its consequences, that it introduces into the life of the mind a significant element of dubiety and alienation which must be taken into account in any estimate that is being made of the present fortunes of mind?

Trilling's chillingly accurate assessment has implications far beyond the concerns of a few academics. It would be a great error to dismiss

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it as the parochial anguish of intellectuals, unmindful of the dangers in the real world, a world where over half a billion people cower at the edge of starvation; where some fifty thousand nuclear warheads stand ready; where numerous states subjugate their people under totalitarian rule; and where even the majority of citizens in our democracy regularly fails to exercise its right to select who will govern. On the contrary, there is a direct link between those problems and Trilling's observation. As he noted at the end of his lecture, "this falling off [of the confidence of the power of mind] must be felt as a diminution of national possibility, as a lessening of the social hope. . . . *Mind at the present time draws back from its own freedom and power.*"

Trilling reveals both the intellectual and the political consequences of being denied knowledge without which some of our best thinkers cannot be sure they have a proper hold on the world. This sense of impotence in the face of the social and political decisions being made for us in this scientific age mirrors a fact that has even been documented in opinion polls: It used to be the case that the more educated the individual, the more he approved of science. Distrust was greatest among the least educated. Now there has been a complete reversal; the distrust is least among the most naive. From among the others we are beginning to hear the sentiment with which Bertold Brecht ended his play, *The Life of Galileo:* "In time you may discover all there is to discover—but your progress will only be progress away from mankind. The gulf between you and the people will become so great that one fine day you will cry out in jubilation over a new achievement—and be greeted by a cry of universal horror." William Faulkner, in his acceptance speech for the Nobel Prize, said simply: "There are no longer problems of the spirit. There is only the question: When will I be blown up?"

* * *

I have been pointing to a polarization that is pitting two groups, once allies, against each other: one, chiefly scientists and their followers, including technology enthusiasts, is cheered by the promise of ever greater scientific advances; the other is depressed and fearful in the wake of these very advances. How did this separation come about?

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We must look first *into the intellectual machinery of scientific advance itself,* to see what is causing these antipodal trends. Is there one common reason for both the euphoria and the despondency? How can an activity be seen as the isolated, esoteric pursuit of a few souls engaged in rapturous contemplation, and also as the dominant, perhaps uncontrollable force directing the very course of society? What is there about modern science that makes it so successful in the hands of relatively few, and so difficult or ominous for the rest?

A key to the answer will be to see that the progress of science and of science-based technology follows a pattern that is built in, and rather different from the progress of other activities. This order conflicts with the layman's impressions, produced by the daily stream of cheerful announcements of new findings and new products, emanating from university laboratories and technology-based industry. Their sheer quantity and lack of coherence must be as disorienting to the average person as the cacophony of events that buffeted Tolstoy's Pierre while he stumbled through Napoleon's battlefield. But despite their appearance of randomness, scientific and technical advances reflect a development akin to tree-like growth, a motion with two components: one vertical, toward a higher, more abstract state of scientific specialty; the second horizontal, branching toward the sides, where applications and repercussions radiate into other fields, from engineering to literature. This two-dimensional unfolding can be traced over history. Some components of the development indicate a tendency toward discernible goals—more so for the physical sciences, to which I shall necessarily restrict my specific examples, and less so for some of the other sciences, although in this respect they are all qualitatively similar. We shall find that the model of tree-like growth helps us understand the two main benefits of the advancement of science, and also the two main burdens.

* * *

First, consider the order associated with the upward thrust of science. It is motivated by a constant search for unities and simplicities behind nature's spectacle of variety, a reaching for ever higher, more general conceptions that allow one to see common features among the phenomena. I must insert here a disclaimer: Like all who have

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struggled with this question, I find it utterly mysterious that this search should be so successful—why, for example, the mathematical equation that applies to acoustic waves should be applicable again and again in widely different contexts, from the spreading of temperature profiles to the motion of elementary particles; or how ideas developed in the study of macroscopic phenomena such as superconductivity should turn out to be well adapted to deal with submicroscopic problems concerning the structure of nuclei. I recall a physicist asking, "Why is quantum theory possible at all? Why should a theory which you can write down essentially on one page apply correctly to untold billions of individual cases?" It is fitting to recall Albert Einstein's confession in his letter to Maurice Solovine concerning "the high degree of order in the objective world": "One has no justification to expect it *a priori*. Here lies the sense of 'wonder' which increases ever more with the development of knowledge."

Leaving aside the incomprehensible roots of its success, we do know what stimulates the search for unities and simplicities at ever higher levels of abstraction. While it takes seemingly different forms in different sciences, the upward thrust has been motivated in the physical sciences by the frank desire for "*the complete [intellectual] mastery of the world of sensations.*" With these words, Max Planck, inventor of the early quantum ideas and author of the book *Where is Science Going?* (1932), answered the question posed by his title. That aim—reaching for omniscience about the world accessible to positive science, and hence for a complete scientific world picture—and the way to attain it, might be called the "Newtonian Program," because Newton, while not the first or last to embrace it, adhered so explicitly to it.

In the Preface to the *Principia,* Newton described his aim and procedure: The observable phenomena (e.g., the fall of objects to earth; some celestial motions) led him to postulate the existence of one general force of gravity by which all bodies attract one another, and from this he was able to deduce in detail "the motion of the planets, the comets, the moon, and the seas." But no sooner had he acknowledged this stupendous achievement than he added, with a hint of his deep disappointment: "I wish we could derive the rest of the phenomena of Nature by the same kind of reasoning from mechanical principles." These would include optics, chemistry, the

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operation of the human senses. There was the Holy Grail: the mastery of the whole world of experience, by subsuming it ultimately under one unified theoretical structure. Einstein similarly taught that "the noblest aim of science" was the attempt to grasp the "totality of empirical facts," leaving out not "a single datum of experience." Newton hoped even to go beyond that, to an understanding of the Godhead itself, as well as to the laws of social behavior. As he wrote in the *Opticks:* "And if natural Philosophy in all its Parts, by pursuing this Method, shall at length be perfected, the Bounds of Moral Philosophy will also be enlarged. For so far as we can know by natural Philosophy what is the first Cause, what Power he has over us, and what Benefits we receive from him, so far our Duty toward him, as well as that toward one another, will appear to us by the light of Nature."

Even without this additional aim, and similar ones proposed by the physiocrats of the eighteenth century and the technocrats of the twentieth, the ambition of the scientists' Newtonian Program is breathtaking. To understand better its dynamics, consider the pursuit of the Newtonian Program in terms of a simple diagram. Imagine a horizontal plane on which each point corresponds to a datum of experience, an observation, or a sensation. For example, in the left corner of this plane are points that represent observations of regular planetary motions, from Hipparchus to Tycho Brahe and onward. Next to it, to the right, are points representing the trajectory of projectiles and the falling of an apple; the data of motions of comets; the motions of the moon; the behavior of the tides; the shape of our spinning earth; the variation observed in the time kept by pendulum clocks at different parts of the globe; the propagation of sound and motion in fluids generally. Further toward the right side of this vast plane of experience are the data obtained from various phenomena of optics, from rainbows to diffraction. Beyond that is the curious behavior of charged amber, of currents, magnets, chemical reactions, and so on: the whole accumulation of the "facts" of nature that, at first glance, have little in common with one another.

One way to understand what I have called the Newtonian Program is to see what Newton did with this material. Observation of the phenomena at the left side of the plane led him to propose the existence of a universal force of gravity that diminishes with the square of the distance between bodies. To this postulated force

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Newton added what he called the three "axioms or laws of motion," some definitions (of mass, momentum, and the like), and a slew of mathematical propositions which nowadays could be greatly condensed. Together, the postulated force, the laws of motion, and the propositions formed Newton's axiom system, suspended above the plane of experience. The reason for this construction was to make logical deductions that were inherent in the axiom system, and to see whether these deductions coincided, or at least were not incompatible, with the known facts, i.e., the "points" on a good portion of the plane of experience below.

The Newtonian synthesis was an overwhelming success because it allowed a wealth of apparently disparate phenomena to be related in a very economical way, by seeing that they coincided with deductions from one simple, mechanical axiom system. Moreover, as new phenomena came into view, such as the motion of Uranus and Neptune, the rotation of the galaxies, and other previously uncharted extensions of the plane of experience, they too fell into place under the same "pyramid" formed by the initial axiom at the peak and the deductions radiating down from it.

The next major advance of that sort was Hans Christian Oersted's achievement in 1820, showing that two other, similar pyramidal structures—one accounting for static and current electricity, and the other for the phenomena of magnetism—could be regarded as subsets within a larger and higher pyramid. Oersted found that a magnet needle could be deflected by an electric current, that currents surround themselves with magnetic lines of force. In this way, magnetism and electricity were fused into one conception, the first such unification of apparently separate forces of nature. Oersted's publication provoked an explosion of scientific work, including the discoveries of Ampère and Faraday. Technical applications followed quickly, starting with an electric telegraph.

Half a century later, the plane of experience had become crowded with many more discoveries, but the urge to achieve synthesis had succeeded again, and raised further the height of the axiom system embodied in the structure of physical theory. Maxwell was able to show that the phenomena involved in the propagation of light could be brought under the same roof with the unification of electricity and magnetism that Oersted had discovered. It was another achievement

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on the scale of Newton's, showing that phenomena that appeared diverse were really closely related.

Advances in the physical sciences have continued in this same style. The experiential horizontal plane has become more extended and the upward thrust remains powerful. One set of phenomena, such as the emission of beta rays in radioactivity, has been interpreted as the action of a force called the weak nuclear force that acts among leptons (of which the electron is an example). Another large set of nuclear phenomena is now understood in terms of the strong nuclear force acting among quarks.

Einstein had nourished the lifelong hope that a theory could be found to subsume the phenomena involving gravitation and those of electromagnetism under one greater axiom system, incorporating Newton's and Maxwell's pyramids into a yet higher pyramid, a unified field theory. It turned out, however, that this upward movement was achieved in a different way, by uniting the Maxwellian and the weak-force structures under one axiom system, characterized by the action of the "electro-weak" force.

Our attention is now focused on the next candidate for further unification, at yet a higher level of new axioms. The name "grand unified theory" has been coined for it. When the fog lifts, the two peaks symbolizing the electro-weak force and the strong force should turn out to have been just the lower portions of a still greater mountain range. If that is true, leptons and quarks would be related, and a lepton-quark conversion, indicated by the decay of protons, should be observable. This further widening of the plane of experience involves exacting experiments to bring into view phenomena that had not even been thought about previously. And beyond that? The attempt will surely be to subsume all four forces—gravity, the electromagnetic, the weak, and the strong force—in one theory, a tentative version of which is referred to simply as "supergravity."

In this schema of the Newtonian Program much has been left out, not least the intense analytic activity in the lower foothills without which these upward synthetic thrusts would not be possible. As in the building of the Rocky Mountains, a vast amount of energy has to be supplied from the base. Here it takes the form of painstaking experiments to test the flexibility and limits of provisional theories. Nor have I dwelt on a curious consequence of this mode of advance,

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namely, that it constantly cannibalizes earlier achievements, incorporating the useful parts within the newer setting. The labors of scientists are not really cumulative; rather the new growth makes the old invisible by absorbing it. This is, of course, one of the chief differences from the arts and literature, in which each work retains in principle its individual claim to respect from later practitioners or the public, and perhaps also maintains continued vitality as a source of new inspiration.

Despite its limits, the model I have proposed does illustrate that science, in the words of the philosopher W.V. Quine, is not an assemblage of "isolated bits of belief, but an interconnected system which is adjusted as a whole to the deliverances of experience." The schema also indicates why this audacious method of construction does *not* result in the Tower of Babel: it is at the bottom of the schema that the various languages are spoken, whereas at the top they all become one. In addition, it helps to understand the historic fact that science seems to follow what Alexandre Koyré called "an inherent and autonomous" development. Finally, this outline sketch may explain why the success of the enterprise can on occasion release high expectations and imperialistic ambitions. The physicist Leon Rosenfeld, writing about the 1920s, reported: "It is difficult to imagine the enthusiasm, nay the presumptuousness, which filled our hearts in those days . . . . A friend of mine expressed his view of our future prospects: 'In a couple of years,' he said, 'we shall have cleared up electrodynamics; another couple of years for the nuclei, and physics will be finished. Then we shall turn to biology.' "

A single-minded, optimistic spirit grips the community of scientists engaged in today's high-metabolism, high-stakes enterprise. They seem to be caught up in the promise that perhaps in our own lifetime we shall really know why electrons, protons, and neutrons exist; what the life cycle of the universe is, from the initial Big Bang to the final Big Crunch; and what the connecting links are between the various states of organized matter, from atoms to living things to societies. Few scientists doubt that the Newtonian Program can eventually be completed, and few could think of a better way to invest their lives than in that grand project. Measured by its own criteria, scientific research has never been of higher quality, or the prospects greater that the best is just over the horizon.

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One answer to the common, plaintive question "Where is science going?" is therefore the practical response of most scientists: If you give us the means, and a flow of spirited young people to assist us at the frontiers of inquiry, and if the sciences are allowed to follow their own manifest destinies, there is virtually no limit to their continued perfection. The haunting promise is that we may achieve a panoramic view of the whole physical world, one that will allow the mind's eye to obtain, at a single glance, a unified perception of all physical events, causes, and effects. In Einstein's words: "The confident belief that this ultimate goal . . . may be reached, is the chief source of the passionate devotion of the researchers." Even if that great project proves endless, it now provides science with a purposeful drive toward a goal, a *telos*. Even though there are always many more "diversifiers" than "unifiers," the vision of the latter helps organize the smaller local tasks; it tides us over the inevitable periods of stagnation and failure; and it will continue to stimulate the community long after our current achievements have come to look small from the new heights.

In the exact sciences other than the physical ones, the upward thrust toward a more encompassing view has been organized on different lines and around other key conceptions. Such differences are of immense interest to the historian of science, but are not significant here, because what will concern us shortly, as one set of consequences of the mode of advance I have sketched, are the *costs* of this method of achieving a scientific world picture—and these costs are much the same for all scientific fields. Yet, before we turn to that, I must refer briefly to the second process in the unfolding of science, the outward movement to the right and left. Here we shall be concerned not with the building of higher conceptual structures in the pursuit of omniscience, but with the primarily instrumental aim of increasing human power through "mission-directed" research.

* * *

For the purpose of illustration, it will be useful to refer to a specific case, such as the targeted research project in 1946–48 that led to the transistor, and for which the 1956 Nobel Prize for Physics was awarded to John Bardeen, William Brittain, and William Shockley of

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the Bell Telephone Laboratories. Unlike the classic "pure" or "basic" research which generally starts and ends in the minds of scientists, this development quickly triggered a proliferating set of devices, from heart pace-makers to high-speed computers—devices that have begun to change civilization itself, including, indeed, how basic research can be done effectively in the sciences and in some areas of the humanities.

At the ceremony presenting the three Nobelists to the King of Sweden, E.G. Rudberg of the Royal Academy in Stockholm compared them to the "small party of ardent climbers" who have reached the "summit of Everest," even though they had started their assault from a high-altitude camp that "more than a generation of mountaineers had toiled to establish." Such an image applies to the Newtonian Program of autonomous, basic research, but it is not really appropriate for this case or others of the type. A historical study would quickly show that many factors essential to the achievement of these scientists were absent from the typical project we discussed earlier—most important, a mission orientation, embodied in the institutional policy of the Bell Laboratories, announced in 1945, to obtain "new knowledge that can be used in the development of completely new . . . elements of communication systems." The pressure during World War II to develop rectifiers acting as crystal detectors for radar provided a strong impetus, as did an old hope of making amplifiers that avoid the power drain of vacuum tubes, and switching devices without the usual problems of corrosion and slow response. The work was "problem-focused"; it depended as much on the expectation of relatively short-term payoff as it did on the quantum physics of the 1920s and 1930s.

When the three scientists were later interviewed, they revealed that much of their success depended also on "extraneous factors," for example, the particular style of work of the laboratory—a pragmatic experimentalism nourished by the rather American mix of science, engineering, and improvisation—and on the mobility of young scientists seeking to train under skilled teachers. In short, the three who made it to the top of Everest were much helped by other mountaineers, by Sherpa porters, by supporting organizations near and far, and by a mandate for useful results.

The mission-directed style of research usually leads to both intended and unintended changes in current technology, engineering,

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medicine, or agriculture, and so affects the social matrix much faster than do the results of basic research. This penetration may be represented by a diffusion of effects from the realm of scientific concepts into the polity, a lateral outreach that is not a mere by-product but a chief aim of mission-directed research. In essence, the motivation here is instrumental. This style of work might be termed the "Baconian Program," for it was Francis Bacon who urged the use of science in the service of omnipotence, "the enlarging of the bounds of human empire, to the affecting of all things possible."

Whether the title is quite appropriate is unimportant. The significant fact is that in our time a remarkable symbiosis has established itself between the Newtonian and Baconian Programs. There have always been occasional cross influences—historians of science are still debating whether Galileo learned more from the workers in the Venetian shipyards, or they from him—but now these two approaches have come to interpenetrate each other thoroughly, just like two mechanical systems that exchange energy more rapidly and vigorously while they resonate with each other. The "pure" and the mission-oriented versions of research send their respective products back and forth, increasing their own rate of advance as they do so—tightening their coupling further, and also blurring the distinction between them.

The marriage of science and technology is undoubtedly permanent and beneficial to each. The experimental side of science has become more technological (the sealing-wax–and–string era of laboratory work ended when World War II technology was declassified), and engineering depends increasingly on a scientific base. Indeed, the laboratory experiments that confirmed the theory of unification of the electro-weak force depended chiefly on products of modern electronic engineering. Conversely, the design of industrial products of biotechnology follows by only a few years or even months the latest results of basic research in genetics and molecular biology.

* * *

The first main consequence of the advancement of science in our time is one that we may be sure Jefferson himself would have been delighted to see. The accelerating process of unfolding has brought us

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to a fairly coherent overview of nature and the design and production of powerful technical devices, while a cybernetic process of positive feedback allows the continued, simultaneous escalation of scientific as well as engineering advance. Another consequence of this process, insufficiently noted, would perhaps have appealed to Jefferson even more. It is not merely a question of the commonplace observation that our physical burdens have lightened, farm life has been transformed, and medicine improved, but of the direct and indirect influence that the results and attitudes of scientific/technological advance have had in extending the very conceptions of *human rights.* Since Thomas Hobbes, to whom the essence of such rights was merely the freedom to eat and be eaten, moral and legal rights have increased greatly. Scientific findings in biology, anthropology, psychology, and other branches are largely responsible for making us certain, as Jefferson's time was not, of the essential homogeneity of the human race—a fact from which springs the entitlement to protection against discrimination. Biomedical advances have made it possible to respond to the clamor for access to medical care, and to support the right of women to assert choice in family planning. Such examples can be greatly extended.

D.D. Raphael has observed that the various twentieth-century declarations of human rights incorporate as necessities what, in previous centuries, would have been luxuries, and that material advance stimulated the continuous expansion of the definition of human needs. J.E.S. Fawcett, surveying the whole issue of protecting human rights, concluded that "fundamental to all effective methods of implementation of human rights" is the development of scientific rationality itself—"independent and objective fact-finding"—as well as the modern technology of rapid communication and publicity. One fact the discussions on modern theories of rights agree on is, in the words of C.B. Macpherson, that the "theory [of human rights] finds itself in need of development to meet changed conditions," and these changed conditions are to a large extent due to the influence of science and technology on the operations and values of modern society.

Increases in productivity, for example, have quite undermined old assumptions of permanent contentiousness and possessive individualism that were based on the notion of the inevitability of severe scarcities of resources. (One of the early, unexpected results of the

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spread of railways was that local famine became avoidable, and therefore intolerable.) The very increase in the number of charters and debates on human rights in our time may reflect the recognition that central portions of the Hobbes-Lockean "liberal-individualist" tradition, as well as the Rousseau-Marx "anti-bourgeois" traditions, are no longer relevant or sufficient, leaving us with the task of redefining, in the modern context of a technologically driven society, a workable framework for human rights that extends those derived from the Declaration of Independence.

* * *

I shall now turn to the two main consequences of the advancement and symbiosis of science/technology that are of a less happy kind: the new burdens. The first and most obvious of these is loss of contact. Despite popularization by the mass media, the concepts and methods of science have become largely inaccessible to all but its practitioners and a small circle of attentive onlookers. On the basis of an extensive anthropological study, Margaret Mead noted more than two decades ago that both school children and adults in our society had, over the previous fifty years, "come to feel that science is something deficient and alien, a discipline that they neither can nor care to understand." While Americans embrace with delight the products of technological industry, the conceptual base of their operations remains opaque to most, unlike the earlier tools and devices that were relatively transparent and comprehensible.

The intellectual brilliance of our sciences, the ingenuity of our technologies, may be characteristic of our culture, but from the point of view of the public and most intellectuals, the thought processes and operations of both have moved behind a dark curtain. There they have taken on a new form of autonomy—isolated from the active participation or real intellectual contact of all but the highly trained. Contrary to eighteenth-century expectations, the scientists are losing what should be their most discerning audience, their wisest and most humane critics.

This burden is, ironically, caused by the very success of the method of scientific/technical advance. As the process of building a unified scientific world view proceeded, as the conceptual structure grew

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more elevated, the chains between the axioms at the top and the empirical base at the bottom had to extend further. The logical structure reaching down from the axioms became more formal and parsimonious; the bridge to ordinary intuitions and to the rationality of every-day thinking was first stretched, and then was lost or became an actual handicap. While in Jefferson's day it was possible for those in his circle to value and comprehend much of the science not only of Newton's time but of their own, this ceased to be the case for interested onlookers a century or so ago. By now, the instructive metaphor is essentially unavailable, and the barriers of communication are virtually insurmountable even for the interested nonscientist—despite Einstein's warning: "I can think of nothing more objectionable than the idea of science [only] for scientists. It is almost as bad as art for the artists, and religion for the priests."

As the plane of experience expands through the use of specialized or high-technology observational devices, the public progressively loses access to the phenomena of nature. The connection between phenomena and theory, the theory itself, and the way it is constructed, confirmed, and elaborated are, and have to be, fully controlled by the scientific community, and understanding them comes only with long immersion. We can see more clearly one of the chief causes of Trilling's perception. Precisely as science progresses toward its declared goal, and as the rate of its new triumphs increases, the larger yawns the unnegotiated intellectual separation from those standing on the sidelines—all those who feel the shame and sorrow of being excluded "from the mode of thought which is habitually said to be the characteristic achievement of the modern age."

* * *

I must now turn to the second cost, which is also a by-product of the dazzling advancement of the modern science-*cum*-technology complex. It is a cost not to the intellectual power and integrity of our cultural trustees, of which Trilling spoke, but to the political effectiveness of our citizenry. The source of this burden lies chiefly in the fact that the metabolism of the science/technology complex has progressively increased since Jefferson's days. As it continues to do

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so, it enlarges the scale of technological intervention in our lives at the same time as it inhibits our opportunity to evaluate and respond to the ethical and value impacts of these interventions. The old (and sometimes blind) faith in the benign efficacy of technological progress has been waning, even yielding to its very opposite—the fear of an autonomous technology, and the rise of an ideology of *limits*.

The relative modernity of this concern can be illustrated by studying the outcome of the seemingly humble scientific discovery made over a century and a half ago, in October 1831. When Michael Faraday in London put his hand on a copper disk, and made it rotate between the poles of a magnet, a steady electric current was induced in the disk. He had discovered (or invented) the electric generator, or dynamo. The simple gadget was a by-product of Faraday's lifelong search for his true and quite "Newtonian" goal—to find through the study of diverse scientific phenomena the unity of all nature's forces. Faraday's dynamo took the energy his hand gave to the disk, and made that mechanical energy reappear as electrical energy which could be drawn off in the wires connected to the disk.

It might have remained a scientific curiosity, and a mirror image of the motor effect Faraday had found eleven years earlier when pursuing Oersted's findings, but Faraday's new dynamo (and the version Joseph Henry invented at almost the same time) was a source of electricity more effective and cheaper than the battery that Volta had discovered in 1800; it was soon redesigned to use mechanical energy from any source—wind, water, steam, coal, wood, gas, or oil—and to issue forth electrical energy for immediate transmission to distant points, as far as cables could reach. There, motors reversed the process, yielding back mechanical energy to do work; or resistors could convert the electrical energy to heat and light.

The physics involved is not sophisticated, but the effect on society was. At last, the source of energy did not have to be in the same place as the ultimate user, a crucial difference from the steam engine, burdened down by its fire box, boiler, and fuel. The dynamo could be anywhere and produce its effect with high efficiency at a great distance; its action was almost instantaneous, its capacity in principle virtually limitless, the raw material used for the prime mover relatively cheap, and the sanctions against disposing of the effluents practically absent.

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As a result, the total system was immensely potent, indeed irresistible. The dynamo, in hundreds of forms and uses, became the keystone that completed the industrial revolution and the modernization of day-to-day life. The modern city could not have risen without the development of the dynamo, for on it depends essential transportation such as elevators and subways, and all electrical lighting, signaling, communication, and control. Life in the factory, in the workshop, and eventually on the farm was transformed by the new generators, as were industrial processes; the electro-chemical industry, which had initially not been considered a beneficiary when the great Niagara Falls power plant was built, was by the turn of the century using more electrical power than lighting and motors together.

What interests us here is that the introduction of electric power into society and the landscape, while not without difficulties, was a remarkable success. One reason was simply that enough time had elapsed to allow a degree of intellectual and political accommodation. The design of commercially viable generators took nearly fifty years after Faraday's first model, and brought together a great variety of interests—scientific, technical, financial, managerial—in many countries. The various problems of "electrification" engaged citizens at every level, from Parliament and Congress to individual towns and villages. The system that finally evolved was a compromise between divergent interests and alternatives that had been widely debated and considered at length.

Such public involvement is just what is becoming less and less possible as the rate increases at which science-based technology is injected into the life of the nation. Thus the rapid initial deployment in the United States of nuclear reactors for power generation turned out to be a disaster for that industry itself. Concern about the long-range consequences has also been raised by the rapid computerization of the work place, by the introduction of the robotic factory, and by the vast new weapons systems now on the drawing board and in production. These and similar decisions no longer grow out of an organic adaptation among all the relevant interests, a process of evolution in which sufficient time can elapse to allow technical details to be learned and open debate to take place among an informed citizenry. According to a recent estimate, nearly half the Bills that come before the U.S. Congress have a substantial

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science/technology component. Yet few in Congress or on its staff have, or can have, the training and background to be really familiar with the problems. We are reminded of Lord Snow's well-known prediction that in such a climate the decision-making process may be usurped by the " scientific overlords," and of Eisenhower's Farewell Address (January 1961), warning not only of "the acquisition of unwarranted influence . . . by the military-industrial complex," but also of the "danger that public policy could itself become the captive of a scientific-technological elite."

In a recent essay, "Coping with Technology through the Legal Process," David L. Bazelon, Chief Judge of the U.S. Court of Appeals for the District of Columbia Circuit, wrote that "some two-thirds of the D.C. Circuit's caseload now involves review of action by federal administrative agencies, and more and more of such cases relate to matters on the frontiers of technology." In discussing how "society can come to terms with science and learn to cope with technological process," Judge Bazelon concentrates on the central issue that virtually every technological innovation introduced to solve a societal difficulty will also have unwanted consequences—hence will require some painful value choices and difficult policy decisions to be made.

Scientists and engineers do have a role to play, but it is a limited one; for as expert witnesses or advisers they are likely to disagree about some basic facts in the case, and to disagree all the more about value-laden inferences from these facts. These diverse opinions, together with all relevant information, must be put on the table—not in a courtroom, where the judge is unlikely to have even a "speaking familiarity" with the issues, but in a public setting: before the decision-makers directly responsible to the citizenry; in forums that allow public input and participation; before regulatory agencies; and above all before elected legislatures, which, in a democracy, are precisely the bodies intended to make the value choices. Judge Bazelon concludes that this may be a far slower and more cumbersome process than the tempting alternative, where the decision is made by a very few outside the public arena; but that alternative is exactly what must be avoided. He quotes John Stuart Mill:

> Even if the received opinion be not only true, but the whole truth; unless it is suffered to be, and actually is, vigorously and earnestly contested, it will,

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by most of those who receive it, be held in the manner of a prejudice, with little comprehension or feeling of its rational grounds.

* * *

We come here to Thomas Jefferson's lifelong insistence, and the very kernel of his teachings—that citizens are the only safe guardians of their liberty and pursuit of happiness. Not even with the best will in the world can the judges and the courts, the legislators in their ill-attended sessions, or the scientists, engineers, and other specialists advising decision-makers play this role for them. All these together are only part of the framework within which citizens can make their franchise effective. To do that, however, requires an adequate level of knowledge, which must be achieved through a "systematic plan of general education" in schools and colleges and later through continued self-study. To James Madison he wrote in December 1787, while discussing the proposed constitution: "Above all things I hope the education of the common people will be attended to; convinced that on their good we may rely with the most security for the preservation of a due degree of liberty."

For those who are able, Jefferson repeatedly proposed—for the same ultimate purpose—courses of study that were not far from his own at William and Mary, and that put to shame much of what now passes for a typical curriculum. To one of his correspondents (William Green Munford, 1799), who asked about a good reading list for mathematics, Jefferson recommended some Euclid, some Archimedes, trigonometry ("There is scarcely a day in which [every person] will not resort to it for some of the purposes of common life"), the science of calculation through cube roots, quadratic equations, logarithms, and "fluxions" [calculus] as an "added luxury." He continued, "There are other branches of science, however, worth the attention of every man" and necessary for "our character as well as comfort": "Astronomy, botany, chemistry, natural philosophy, natural history, anatomy, [at least] to possess their general principles and outlines, so that we may be able to amuse ourselves and inform ourselves further in any of them as we proceed through life and have occasion for them." His use of the term "science" shows that he had in mind the balance of the major branches of

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knowledge; in addressing Joseph Priestley (in January 1800) his list of sciences includes "Politics, Commerce, History, Ethics, Law, Arts, Finearts."

Not for Jefferson the image of the mind at the end of its tether! On the contrary, he confesses freely to believe, with Condorcet, that man's "mind is perfectible to a degree of which we cannot as yet form any conception." To think otherwise, to harbor the "cowardly idea" that the human mind is "incapable of further advances," was to embrace a doctrine that fitted well the purposes of the "present despots of the earth, and their friends." For in Jefferson's view, the main objective, "the freedom of the human mind," is secured only if the mind is educated or engaged in self-improvement. It is in this sense that (in a letter of 1795 to François D'Ivernois) he identified freedom as "the first-born daughter of science"; conversely, as he told Joseph Priestley in 1810, "ignorance puts everything into the hands of power and priestcraft."

Thus the primary purpose of improving knowledge and understanding was, for Jefferson, not to produce a cadre of scientists and literati; not to design better "protection against foreign power"; not even its necessity "for our character as well as comfort," important as all these were. The foremost purpose, as he put it, lay in the importance of knowledge and informed debate "to the preservation of our republican government."

We would do well to remind ourselves today of Jefferson's threefold preoccupation: that the highest good is the exercise by individuals of their natural rights; that the inevitable excesses of power, if unchecked, lead to oppressive regimes; and that the chief safeguard against this course of degeneracy is the wide dissemination of liberal education. He stated this credo most clearly in his courageous "Bill for the More General Diffusion of Knowledge" (1778). It begins with a manifesto that deserves to be inscribed over the doors of our schools:

> Experience has shown, that even under the best forms [of government], those entrusted with power have, in time, and by slow operations, perverted it into tyranny; and it is believed that the most effectual means of preventing this would be to illuminate, as far as practicable, the minds of the people at large, and more especially to give them knowledge of those facts, which history exhibiteth, that, possessed thereby of the experience of other ages and countries, they may be enabled to know ambition under all its shapes,

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and prompt to exert their natural powers to defeat its purposes . . . . Whence it becomes expedient for promoting the publick happiness that those persons, whom nature hath endowed with genius and virtue, should be rendered by liberal education worthy to receive, and to be able to guard the sacred deposit of the rights and liberties of their fellow citizens . . . .

One may quarrel about the details of a realistic education that could safeguard the mind's freedom and effectiveness, now that the nation has grown vastly from the three million inhabitants of Jefferson's predominantly rural, isolated America. Even allowing for the sophistication of modern knowledge, the complexities of modern problems, and the potentially more calamitous results of bad decisions, one may consider his curriculum "worthy of the attention of every man" to be unreasonably demanding. However, national policy does respond to its leaders' expectations.

Yet, the evidence points to a catastrophic reduction of the normal expectation and preparation in the education of our future citizens. The findings are chilling in every field, and those for the sciences merely typical. A carefully assembled study by the National Academy of Sciences for the President in 1980 concluded that the current trend is a tailspin "toward virtual scientific and technological illiteracy." Moreover, as if to thumb its nose at Fate, the next administration began in 1981 to phase out federal support for science education at the college and precollege level—the only industrial country to do so.

The need for an informed and confident citizenry to assure that the processes of democracy continue to work has not diminished. The very opposite is the case. In addition to adopting the role of alert watchdog of national and local policy, we all bear the burden of making personal decisions whose soundness depends on our ability at least to ask questions about their technical context. Everyone is caught in this vortex: the engineer who discovers in mid-career that, while he knows how to design a new plant, as he was trained to, he now has to learn how to evaluate the ecological impacts; the administrator forced to deal with ambiguous scientific data or probabilistic risk-benefit analyses in some economic dispute; the board chairman as well as the greenest worker, when the old office is turned over to electronic machinery and the shop floor is automated; parents having to decide what processed food to feed their child; the doctor or clergyman when faced with ethical problems raised by new technologies that allow us to initiate, prevent, or end a life at will.

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If one has no base on which to formulate probing questions, can one actually give informed consent to planned surgery? How can jobs be designed for people who are not skilled or numerate? How is the issue of privacy affected when bank accounts are absorbed into the electronic fund transfer system? How does one react in an informed way—that is neither hysterical nor techno-enthusiastic—to a plan for siting a power plant nearby, whether nuclear or not?

There are a few inspiring examples of collaborations between scientists and the public, bringing enlightened solutions to complex technical problems that face the nation. One is the cessation in the early 1960s of nuclear weapons testing in the atmosphere, chiefly as the result of a major educational campaign mounted by scientists and others concerned about the health dangers of radioactive fallout. (One congressman was reported to say: "When parents wrote me that Strontium-90 from fallout was getting into their children's teeth and bones, I knew I had to pay attention: they were spelling Strontium correctly.") A second, more recent example was the debate about the safety of laboratory experimentation with recombinant DNA, which was finally resolved in a manner satisfactory to practically all involved. Both these and a few other such instances had in common patient educational efforts and protracted debate among scientists and groups of laymen.

For just that reason, these are the exceptions. As a rule, there is not enough time or talent to build up successful communication between groups of concerned scientists and voters to help form a national decision agreeable to each. Technical details are (or at least seem) so complex to the layman, and their initial base of knowledge is so frail, that serious effort is discouraged. This is most evident today in the difficulty of conducting a meaningful debate on weapons policy. The arms race is full of absurdities, not the least being that it is a grotesque offspring of a perverse coupling, in each country, between international, unifying science and parochial, aggressive nationalism. The worst of these absurdities is that the arms race, with all its costs and dangers, has long since ceased to be reasonable on grounds of national security. Larger and more expensive systems are being designed and deployed that at best will have only marginal value in terms of security, and are far more likely to divert resources and destabilize the fragile geopolitical equilibrium.

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The purely technical facts, widely accepted among competent evaluators and accessible with some effort to any seriously interested citizen, point to the wisdom of calling a halt, especially to the accumulation of nuclear arms. Indeed, beyond one hundred or so weapons on each side, deterrence is saturated. What drives the race now, in both superpowers, are political and perceptual rather than technical factors, perceptions of power rather than physical realities. It would be a triumph if this fact could be made clear to the citizens of the nuclear powers. One of the main obstacles is surely the widespread inability or unwillingness to handle key concepts of a technical kind. Even political leaders with the right intentions and good scientific advice have been disabled by the fear of backlash. We now learn from those close to President Kennedy that in July 1963 he felt unable to follow the recommendation of his scientific-technical civilian advisers to sign an agreement on a complete nuclear weapons test ban with the Soviets, including an end to tests of significant size not only in the air, sea, and outer space, but also underground. Such a comprehensive agreement—which Eisenhower had also considered essential—could have changed world history by containing the nuclear weapons race at that point, and incidentally would have preserved the technological advantage the United States had then. The Soviets, in a notable departure from past positions, were prepared to accept two or three annual inspections on their soil for monitoring suspected cheating. Technically, this was sufficient, for it provided a good probability of discovering really dangerous new developments (involving a long series of tests, rather than one or two that might escape notice). Moreover, better seismographic monitoring at a distance without on-site inspection could be, and soon was, achieved to provide further deterrence against breaking the offered agreement.

Yet, Kennedy did not dare ask Congress for such a treaty. He felt, probably correctly, that despite all its advantages, the proposal would be rejected because it was based on concepts of probability—one of the notorious blanks in modern education. As the ensuing debate showed, a majority of citizens, unfamiliar with the rudiments of probability, required a higher (and, to the Soviets, unacceptable) number of on-site inspections, in order to feel that they knew "for certain"—even though the only certainty was that the lack of a comprehensive ban would assure the dangerous and costly continu-

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ation of the nuclear menace, the inevitable increase in the size, variety, and proliferation of those weapons, and the introduction of additional systems.

The Academy report I quoted earlier warned that "important national decisions involving scientific knowledge will be made increasingly on the basis of ignorance and misunderstanding." As the divergence widens between those who make policy and citizens who lack the knowledge to assess their proper interests, the threat increases: the nation is in danger of being torn in two. The wound already felt by sensitive humanists such as Trilling must sooner or later become a traumatic separation—the most ironic cost of the advance of the modern science/engineering complex. On one side of the gulf will be a relatively small, technically trained elite, consisting chiefly of scientists, engineers, technicians, and other highly skilled individuals, amounting to a few percent of the population. As an increasing proportion of major decisions have a scientific/technical component, they will supply the new potentials as well as advice on how to direct and use them. On the other side will be the huge majority of the people, without sufficient language, tools, or methods to reason or to argue with the experts, to check on the options they present, or to counter either their technical enthusiasms or their doomsday warnings. That majority will effectively place itself in the hands of the elite, perhaps sinking quietly into the comforts and amusements which technology has helped provide. Some cynics may even welcome such a state of affairs, for the ignorant tend to be easier to govern and to divert into militant philistinism.

These new illiterates will be slaves with respect to the key issue of self-governance, a possibility expressed by Cardinal Newman in the *Idea of a University:* "Not to know the relative disposition of things is the state of slaves." For them, in a grotesque reversal of the Enlightenment dream, the answer to the question, "Where is the modern advance of knowledge and power taking us?" will be, "Into a new slavery."

I have chosen that word advisedly. The historian, John Hope Franklin, in his 1976 Jefferson Lecture, reminded his audience of the conditions that helped keep slavery intact in early America. One of these was the denial in the eighteenth century that slaves could *reason*. Jefferson himself once expressed the opinion, although "hazarded with great diffidence," that among the slaves "one could

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scarcely be found capable of . . . comprehending the investigation of Euclid." That was his touchstone. For many eighteenth-century thinkers, slaves would not come under the Law of Nature, which, as John Locke had said, is Reason, and from that law Locke derived the natural rights. In Locke's *Second Treatise on Government,* which Jefferson claimed to know almost by heart as he drafted the Declaration "without the help of books," Locke taught that man has not the liberty to renounce liberty, to renounce being a naturally free being, and to make himself a slave of others. To be a slave, in Locke's words, is to be "degraded from the common state of rational creatures," hence a species apart.

The slaves of the eighteenth century were not given the choice, were not responsible for their shackles. Our new slaves will be different in this respect; for drawing one's mind back from one's own freedom and powers amounts to a willful self-estrangement, a voluntary renunciation of self-government on the hard issues that determine the fate of a people.

* * *

I have outlined the long-range consequences of the intellectual and political costs facing us, largely by-products of the accelerating advancement of knowledge against the background of citizens unable to understand enough to take command of their own destiny. It is a stark picture, and the practical obstacles for the more obvious remedies are formidable. Yet I would not have addressed this issue, had I thought the present course uncorrectable. I have referred to a few of the tools for establishing a new equilibrium, ranging from educational programs to the relocation of at least some basic research into areas where there is some motivation to pursue more Jeffersonian Research Programs, alongside the current Newtonian and Baconian ones. There are others; the nation does not lack good ideas. Rather, it is the scale and seriousness of our current efforts that are inadequate. An assertion of national will and leadership is sorely needed to learn how to live in the modern age while preserving one's dignity and self-governance.

The idea of the "Learning Society" has been the mainspring of every period of civilization, from Athens and the Renaissance to the

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founding of our republic; it must now be broadened to encompass not only Jefferson's person of "genius and virtue," but the whole population. In this way, the hope of the Enlightenment will not be dissipated, and the energies characterizing both the people and contemporary scholarly and scientific advance will be directed to the benefit of each.

* * *

In 1812, Jefferson, then seventy, replied from Monticello to his friend John Adams. Downcast at that dark point in history, he wrote:

As for France and England, with all their preeminence in science, one is the den of robbers, and the other of pirates. And if science produces no better fruits than tyranny, murder, rapine and destitution of national morality, I would rather wish our country to be ignorant, honest and estimable as our neighbouring savages are.

But wither is senile garrulity leading me? Into politics, of which I have taken final leave. I think little of them, and say less. I have given up newspapers in exchange for Tacitus and Thucydides, for Newton and Euclid; and I find myself much the happier.

But Jefferson's native optimism prevails all the same, an optimism we can share if we do not neglect the tasks before us. He told John Adams:

[Your letter] carries me back to the times when, beset with difficulties, we were fellow laborers . . ., struggling for what is most valuable to man—his right of self-government . . . . We rode through the storm with heart in hand, and made a happy port. Still we do not expect to be without rubs and difficulties; and we have had them . . . . And so we have gone on, and so we shall go on, puzzled and prospering beyond example in the history of man. And I do believe we shall continue to grow, to multiply and prosper, until we exhibit an association, powerful, wise and happy, beyond what has yet been seen by man.

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Howard Gardner

Freud in Three Frames: A Cognitive-Scientific Approach to Creativity

THE VISITOR TO VIENNA TODAY FINDS a lovely Central European capital, graced by spacious parks, grand churches, and imposing public buildings, intimate cafes and sweet shops, as well as the vigorous Danube flowing along its broad boulevards. The population is elegant, the theatrical and musical stages mount major productions, and yet it is difficult to avoid the feeling that what was once a world-class city is now a living museum.

Less than a century ago, however, Vienna stood at the center of European political and cultural life. Though not as populous as London, or as historically indispensable as Paris or Rome, Vienna may well have surpassed its competitors in terms of the sheer vitality of its intellectual life. In *fin-de-siècle* Vienna, living within blocks of one another, hobnobbing at coffee-houses and exchanging views at meetings, were such redoubtable figures as members of the Strauss' waltz family, composer and conductor Gustav Mahler, playwright Arthur Schnitzler, philosopher Ludwig Wittgenstein, novelist and essayist Robert Musil, painter Gustav Klimt, architect Adolf Loos, satirist Karl Krauss, librettist Hugo von Hofsmanthal, and physicist

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Heinrich Hertz. Amid this illustrious company lived an individual fully their equal in creativity, who exerted perhaps an even greater influence on posterity: the neurologist, psychiatrist, and first psychoanalyst, Sigmund Freud.

Whatever one's assessment of the scientific status of Freud's contribution, few would question the fertility of his mind or the innovativeness of his contributions to the understanding of human nature. Indeed, Freud ranks with such literary giants as Shakespeare and Tolstoy in his capacity to illuminate human nature; and within the ranks of psychology, his contributions surely match those of William James or Jean Piaget, or, to choose representatives from another sphere of psychology, Ivan Pavlov or B.F. Skinner.

In designating these individuals as creative investigators of the human mind and personality, I am making attributions that should be relatively uncontroversial. As a general rule, there is little question about those few individuals who represent the summit of creativity in a particular field—Mozart or Beethoven, Leonardo da Vinci or Rembrandt, Newton or Einstein. Yet, had I lowered my standards a few notches (Antonio Vivaldi or Jackson Pollock), or singled out an individual work (Beethoven's *Fidelio* or Freud's study of Leonardo da Vinci), I would already skirt controversy.

There may be an important lesson here. Inasmuch as creativity is difficult to delineate and challenging to investigate, it is prudent to begin on solid ground—with individuals and with bodies of work that are uncontroversially creative. While this position may seem reasonable on *a priori* grounds, it in fact represents the view of a minority within the scientific community. To the extent that creative processes have been examined by psychologists and other scientists, attention has fallen on allegedly creative processes in unremarkable individuals or on microscopic examinations of particular moments in the mind of a creative individual.[1] Only a few researchers, chief among them Howard Gruber,[2] have attempted to explain longer-term processes and larger-scale products from a scientific perspective.

In this essay, I attempt to develop a framework that may ultimately illuminate such cardinal instances of intellectual innovation. The framework is multi-faceted and complex—as it must be, if it is to encompass this mammoth subject. I find it futile to deal with creativity at a single level of explanation, be it the genetic, the psychological, or the historical. I find it equally unprofitable to isolate

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a single element as the key to creativity—whether that element be a mental process (bi-sociation or fluency), a personality characteristic (doggedness or flexibility), or a cultural ambience (be it democratic, artistocratic, or totalitarian). Indeed, one of the principal reasons why contemporary scientific accounts of creativity seem so inadequate (if not irrelevant) to creativity *writ large* is that they routinely draw on but a single disciplinary lens: the understanding of creative processes and lives requires a combination of disciplines and perspectives.

In my view, intellectual creativity is a phenomenon much like prodigiousness: as David Feldman has argued, a prodigy comes about only when a wide variety of factors all occur at the same "coincident" locus.[3] So, too, creative individuals and creative products emerge only when a raft of major facilitating factors are operative. It requires the perspectives of several disciplines to bring all of these to the fore.

In what follows, my examples will be restricted to individuals and works that are uncontroversially creative. Both because of his secure status as a creative individual, and because the principal facts of his life and work are likely to be familiar to most readers, I will focus particularly on the case of Sigmund Freud.

DELINEATING THE AREAS OF CREATIVITY

My treatment of creativity rests on a key point, one that may be controversial. It is customary to assume—and, indeed, I have assumed it until this point—that creative processes occur in essentially the same way irrespective of the kinds of material or subject matter involved. On such an assumption, individuals are creative or not, and, if creative, they ought to be able to manifest their creativity across a range of fields. An eloquent spokesman for this position is Samuel Johnson, who once defined "true genius" as "a mind of large general powers, accidentally determined to some particular direction." Tests for creativity are a more mundane manifestation of the same position.[4] Even those who concede the existence of specific talents at the highest level are inclined to believe that individuals creative in one area ought to be able to exhibit similar efflorescence in other fields, were they to put their minds to the task.

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The thrust of much recent work, however, including my own studies in neuropsychology and developmental psychology, suggests that cognition ought to be parcelled into a number of component parts, modules, or factors, each operating according to its own set of principles.[5] According to this contrasting account, cognition consists of such disparate areas as language, logical problem-solving, musical competence, spatial skill, and the like. By a corollary assumption, an individual can achieve a high level of competence, or even scale the heights of creativity in a given area of accomplishment without any necessary implications regarding his competence in other domains of experience. Should this point of view become accepted, one would no longer speak (except in shorthand) of an individual as creative: instead, one would recognize the possibilities of creativity in specific domains, and of individuals who are creative artists, scientists, politicians, or inventors, but who could in no way be substituted for one another.

A first step in studying creativity, then, involves an acknowledgement that there are different arenas of potential creativity, each meriting separate investigation. Given provisional acceptance of the idea that cognition and creativity exist in specific spheres of knowledge or competence, it becomes important to discover *what* those areas are, and how the lines between them might best be delineated. In an earlier work, I proposed a set of seven human intellectual competences or "intelligences," which might serve as an initial list of areas of creativity.[6] However, building on the work of my colleagues David Feldman[7] and Mihaly Csikszentmihalyi,[8] I have been developing an approach that seems more adequate to the immediate task.

Our approach involves the recognition that areas may be delineated differently, depending on whether one assumes a perspective rooted in the bio-psychology of the individual, the structure of an area of knowledge, or the surrounding socio-historical context. Accordingly, we find it useful to distinguish among three levels of analysis:

Bio-psychological Potentials or "Intelligences"

Individuals "at promise" in a particular area as a result of genetic or early environmental factors can advance rapidly in one or more of the seven human intelligences. Ordinarily, it is difficult to observe intelligences at work in pure form, but, in the case of certain exceptional

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children, such as those who are autistic, one can peer at an intelligence with little external interference. The child-artist Nadia who has very highly developed spatial and bodily-kinesthetic skills exhibits these forms of intelligence with crystalline clarity and insularity.[9] Also, when an individual advances with great rapidity, one has the impression that the faculty or intelligence is again operating with relatively little external molding. Musical prodigies like Mozart, or mathematical prodigies like Gauss, give the impression of an intelligence unfolding or expressing itself in pre-adapted form.

In many cases, one can observe a combination of intelligences at work. Thus Freud seems to have been very gifted in at least three forms of human intelligence—linguistic, logical-mathematical, and intrapersonal—and he combined these talents in his scientific and clinical work. It seems likely that individuals who accomplish a great deal would have been "at promise" in relevant areas from early in life; and yet it is certainly possible that effective training methods might allow even individuals with relatively modest endowment to attain a very high level of accomplishment.

The Structure of an Area of Knowledge or Human Accomplishment—Hereafter, Termed a "Domain"

Though initially devised by individuals over the course of years or generations, bodies of knowledge can be examined as phenomena in their own right and analyzed in terms of their principal structures and operations. Taken together, these bodies of knowledge constitute what Karl Popper has termed "World III."[10] Thus anyone knowledgeable about mathematics can examine the field or a particular subfield (like the calculus or topology), lay out its critical features, distinguish levels of competence within the area, and the like. Often, these areas can be examined instructively in terms of their symbolic systems and codes,[11] as well as the requisite skills needed to master these systems. Such domains may map quite closely onto a single human intelligence—as appears to be the case with music or mathematics. However, they may also draw on amalgams of intelligences. Thus a domain like chess exploits logical-mathematical and spatial intelligence and may also require a certain degree of interpersonal sensitivity. The practice of psychotherapy stresses linguistic and interpersonal skills, while spatial and musical capacities assume little importance in that domain.

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A biological potential or "intelligence" may unfold initially with relatively little discernible influence of a particular domain as it happens to be implemented in the individual's milieu. Sooner or later, however, intersection with the relevant domain(s) in the culture becomes a virtual inevitability (except in the case of severe pathology). Indeed, any individual who would engage in creative work must situate himself in relation to one or more domains. At any particular historical moment, the person in question possesses a certain level of knowledge or mastery of the domain. Also, the domain itself stands at a certain level of development, featuring its own problems, questions, unresolved issues, and the like. The ultimate creativity of an individual is constrained in important respects by the level of development of the field at the moment when he confronts it. Thus Einstein encountered the domain of physics at a time when many fundamental assumptions could no longer reasonably be sustained; his contribution was to reconfigure the domain in ways that proved acceptable for a considerable period of time. Arnold Schoenberg first encountered music at a time when Western diatonic music was entrenched, but he eventually responded to incipient trends of polytonality and atonality by devising his own system of fully atonal or twelve-tone music. Freud was working initially in the relatively well-defined domains of neurology and neuroanatomy, but soon began to pursue issues that did not fall within a recognized scientific domain and that may well have been subsumed in earlier times under the purview of literature, religion, or folk medicine.

Individuals manifesting their own peculiar blend of intelligences must somehow learn about and become engaged with the domains within their culture. This engagement sometimes occurs through "crystallizing experiences" where a chance (or planned) encounter with some hitherto unfamiliar material or problem has a dramatically motivating effect on the individual.[12] Subsequently, individuals become involved in one or more projects drawn from the domain. Initially these projects are presented by teachers or drawn from books or other media, but ultimately the projects become those of their own devising. An individual working on projects that are promising within a given domain has the opportunity to make a creative contribution to that domain.

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The Social "Field"

The field may be defined as the social organization within which individuals and domains exist and interact.[13] When individuals become involved in a particular endeavor or domain within a particular society, they are necessarily operating within a field. A physicist like Einstein does not simply devise a theory of relativity free of supporting contexts. He learns about the domain of physics through conversing with physicists, reading books, taking courses, writing papers, exchanging them with friends, attending and making presentations at meetings, and the like. A composer like Arnold Schoenberg does not simply inject twelve-tone music into a void, or for that matter, a randomly selected Viennese concert hall. Instead, he masters the existing musical literature, begins to compose, has his compositions performed and reviewed, gathers students around himself, promulgates his new ideas, and is either welcomed or scorned, immediately and over a more prolonged time.

Contrary to popular mythology, Freud did not reach his conclusions in indifference to his surroundings. Beneficiary of some of the greatest teachers of his age, having close confidants on whom he could rely, Freud had the opportunity to relate his ideas to scientific researchers and to medical colleagues. Once it became clear to him—and to others—that he had forged an innovative theory of personality and an apparently effective form of treatment, much of the rest of his long life was dedicated to the founding and furthering of a new field—that of psychoanalysis. Future clinicians and scholars then had the opportunity to develop within this recently evolved field—but not without considerable struggle in many cases.

Just as projects serve as the interface between the individual and the domain, social institutions serve as the intermediary between an individual and the field. It is through participation in social institutions—be they schools, museums, laboratories, journals, meetings, or an apprenticeship system—that an individual who aspires to work in a domain becomes engaged with the relevant persons and secures access to the proper platforms.

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CREATIVITY: A CHALLENGE TO COGNITIVE SCIENCE

An Introduction to Cognitive Science

Our three perspectives provide initial inroads to the phenomenon of creativity. Though these three frames were developed within the domain of psychology, they reflect three quite distinct foci in psychology: biological, epistemological, and social. One can attain an even broader view of these matters by drawing upon a wider range of disciplinary perspectives.

In recent years it has become apparent that issues of the mind transcend the boundaries of any single scientific discipline. These joint realizations gave rise in the last decade to the formation of a new discipline—or supra-discipline—called cognitive science. Inspired in many ways by the advent of the digital computer, and fueled by intriguing historical convergences in several neighboring disciplines, workers in philosophy, psychology, linguistics, anthropology, neuroscience, and artificial intelligence have banded together in order to tackle major outstanding cognitive issues—ranging from the nature of perception to the assessment of human rationality.[14]

Cognitive science is still in its earliest phase and it may be premature to evaluate the achievements of this aspiring discipline, let alone to predict its future. Yet it does seem clear that, if cognitive science is to fulfill its promise, it will ultimately have to tackle the most formidable issues concerning the human mind. It is perhaps fitting, therefore, that a self-styled alliance of the disciplines of the mind direct some of its powers to a consideration of one of the most difficult—but also most alluring—of cognitive issues: the nature of human creativity.

In truth, few individuals who term themselves cognitive scientists have focused on creativity. The topic seems too large, too elusive, still ill-defined. It may not be too early, however, to sketch out the form that a cognitive-scientific approach to creativity might one day assume. Such an approach builds on the trio of perspectives being developed by my colleagues and me: the neuroscientific and the psychological tie in most directly with an "intelligences" view; the cognitive psychological and the artificial intelligence stances link to a "domain" view; the anthropological and historical approaches reflect a "field" view.

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In the remainder of this essay, I shall suggest some of the features that such a cognitive-scientific account might exhibit. As noted, my principal example will be the life and work of Sigmund Freud. It should therefore be stressed that I am not a scholar of Freud and that Freud is used here for illustrative purposes. I rely heavily on Ernest Jones' comprehensive biography.[15] Rather than hinging on the precise facts of Freud's biography, the ensuing discussion is animated by the kinds of questions his life raises and the suitability of cognitive science for addressing these questions.

Psychological Approaches: The Intelligences and the Person

Psychology, and particularly cognitive psychology, plays a central role in any cognitive science, and particularly so in the study of a single creative individual. A psychological approach to creativity may begin with an examination of the cognitive strengths or intelligences possessed by the subject. Ultimately, such an approach should also model the processes exhibited by the subject at work and the ways in which his principal creative products are mentally represented over time.

Creativity extends beyond these cognitive-psychological boundaries. Issues of personality, motivation, and individual style are pertinent to the establishment and maintenance of a creative life. So too, the social circle in which the individual spends his life—in particular, his friends and his family—must be taken into account. Thus, though its falls outside the purview of cognitive psychology as usually defined, our psychological account must incorporate social and personality factors and indicate how these interact with cognitive factors in a given life.

Freud's biographers make clear that he was an individual who would be considered highly intelligent by almost any definition—lay or technical. He attended high school a year before the normal age and stood at the head of his class for the last six years. His position was so special that he was hardly ever questioned in class and he graduated *summa cum laude*.[16] His father, himself an intelligent man, once declared, "My Sigmund's little toe is cleverer than my head."[17]

It is possible to pinpoint Freud's gifts. His linguistic memory was astounding. He had photographic recall throughout childhood and adolescence, which allowed him to glance at textbooks and then

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remember wording exactly.[18] In later life he remembered many passages that he had once committed to memory in childhood in a variety of languages.[19] He invariably lectured without notes and had no need to prepare; in his own words, "I must leave it to my unconscious."[20]

From a "multiple intelligences" perspective, it appears certain that Freud was extremely gifted in language. In addition to the evidence of linguistic memory that I have just reviewed, Freud easily learned English as a child and read voraciously in that language. He was competent in French, quoted comfortably from Latin, and learned Spanish in order to read Cervantes in the original.[21] He was especially gifted as a translator, skillfully recreating John Stuart Mill from the English and his teachers Charcot and Bernheim from French. According to Jones, "he would read a passage, close the book, and consider how a German writer would have clothed the same thoughts—a method not very common among translators. His translating work was both brilliant and rapid."[22] He was able to write with extreme rapidity, and with hardly any need for revision. In 1915, aged fifty-nine, he wrote five of his most original and profound essays about metapsychology within a six-week period. Jones comments, with perhaps a shade of hyperbole, "That they could all have been composed in the space of six weeks seems scarcely credible; yet it happened. Such a furor of activity would be hard to equal in the history of scientific production."[23] Then, in the next six weeks, he went on to write five more essays. Small surprise that in 1930, Freud was awarded the coveted Goethe Prize for writing.

Before Freud entered psychology his major work had been in the domain of neuroanatomy, where he made a number of important though not epoch-making discoveries. It would seem probable, therefore, that Freud possessed a high degree of logical-mathematical gifts, the kinds of abilities on which scientists characteristically rely. The tightly reasoned quality of many of Freud's writings—in particular the *Project* of 1895 and the metapsychological essays of his mature years—convince me that he had considerable logical-mathematical intelligence. It is therefore interesting to note that he himself disagreed. Often he would decry his lack of intelligence, and it seems clear that he had in mind a deficiency in logic and mathematics, which kept him from performing at the very top of these areas of knowledge. He complained that he had not been given

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"a better intellectual equipment. . . . I am not really a man of science."[24] He once declared "my chief reproach to the Almighty would be that he had not given me a better brain."[25] At another time Freud added, "I have very restricted capacities or talents. None at all for the natural sciences; nothing for mathematics; nothing for anything quantitative. But what I have, of a very restricted nature, was probably very intensive."[26]

Lest it be thought that Freud simply had an unjustifiably low opinion of himself, it is instructive to see how he viewed his own powers. Rather than regarding himself as a scientist, or even a scholar, Freud thought of himself as an individual of great curiosity, with a compulsion to understand and to speculate.[27] As a youngster, he had been fascinated by military matters and had strongly identified with the great military leaders of the past.[28] While a career in the armed services was not an option for a Jewish lad growing up in the Hapsburg Empire, Freud persisted in seeing himself as a conqueror or "conquistador." Fiercely ambitious, he cast about for a domain where he could make a major contribution. Having once decided on a medical career, he searched widely for an area of science in which he could stand out. Having found himself unsuited for many areas of study, he eventually gravitated toward neuroanatomy, a specialty for which he felt his own configuration of talents was in fact suited.[29] Within the neural sciences, he evinced early on a preference for examination and observation, rather than experimentation: as Jones puts it, "a preference for the eye over the hand." Neuroanatomy remained for Freud a favored area of study, but when he confronted the fact that others were more likely to reach the pinnacle of that domain he began to cast about for an area to which his own gifts were still more exactly suited.

Freud attributed his ultimate success less to his intellectual endowment (about which he remained ambivalent) than to his habits of character. As he put it, "my whole capacity for work probably lies in my character attributes and in the lack of any marked intellectual deficiency . . . I know that that admixture is very favorable for slowly winning success."[30] Indeed, on the ambitious scale of accomplishment against which Freud measured himself, success did come late—it was only in his late thirties that he began to probe the areas for which he would ultimately be acclaimed. This turn of events did not surprise Freud, for he saw himself in opposition to very potent forces

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within his profession and knew that he was working in an area that was highly speculative and fraught with scientific traps. It is worth noting that the domain of psychoanalysis is an area where achievements have routinely come late in life: indeed, according to John Gedo, analysts almost never make major contributions before the age of fifty.[31]

Excellent work habits, a dogged determination, powerful linguistic and adequate logical abilities were enough to ensure that Freud could become a respected scientific worker but not a world-class creative individual. In Ernest Jones' view, Freud's most irreplaceable gift was his ability to find in an isolated fact the key to a central puzzle. "When he got a hold of a simple but significant fact he would feel, and know, that it was an example of something general or universal. . . . When Freud found in himself previously unknown attitudes toward his parents, he felt immediately that they were not peculiar to himself and that he had discovered something about human nature in general: Oedipus, Hamlet, and the rest soon flashed across his mind."[32] It is worth remarking that this ability to discover pregnancy in an isolated fact is often a hallmark of a scientific genius,[33] but that this talent also entails the possibility of jumping prematurely to an erroneous conclusion. In fact, Freud's career is punctuated with just such instances, ranging from his mistaken view of cocaine as a miraculous cure for all manner of illnesses to his belief, which he later rejected, that all hysteria derives from a traumatic seduction in early childhood.

Freud taught us that the keys to an individual's later life can be found in his earliest years, and he serves as an eloquent exemplification of his own assertion. His early life was marked by a series of signs that he was special: he was born in a caul; an old peasant woman asserted soon afterwards that an important person had been placed into the world; when he was twelve, a passing poet versified that he would become a cabinet minister.[34] He was the eldest of seven children and, from all reports, the strong favorite of his mother: as he once declared, "people who know that they are preferred or favored by their mother give evidence in their lives of a peculiar self-reliance and an unshakeable optimism which often seem like heroic attributes and bring actual success to their possessors."[35] Thus Freud's actual formidable talents were reinforced by magical "signs" of his specialness and by unquestioned support on the part of his family.

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While Freud could be highly self-critical and underwent definite periods of depression, he was at base a very confident individual—possibly as a consequence of this privileged early life. He was also combative and tenacious. As he observed to his fiancée in an unguarded moment, "I have often felt as though I had inherited all the defiance and all the passions with which our ancestors defended their Temple and could gladly sacrifice my life for one great moment in history."[36] On another occasion he declared, "I am nothing but by temperament a *conquistador*—an adventurer if you want to translate the word—with the curiosity, the boldness, and the tenacity that belong to that type of being. Such people are apt to be treasured if they succeed, if they have really discovered something; otherwise they are thrown aside."[37] So to talent and magical signs were added a willingness to confront hostility and a strong inclination to persevere.

Whatever Freud's leanings toward conquering, speculation, and optimism, he succeeded early on in wedding these traits to a strong sense of discipline. A tell-tale marker was his decision to enter medicine, and then the specialty of neuroanatomy, where there was scant opportunity for speculative sprees. In his words, "As a young man I felt a strong attraction toward speculation and ruthlessly checked it."[38] In early adulthood he began the practice of working for nearly all of his waking hours and maintained this demanding schedule until near to the time of his death.[39] Indeed he would devote up to twelve or thirteen hours a day to psychoanalysis, seeing patients until ten o'clock in the evening, and then writing from eleven until the early hours of the morning.[40] Even in his infrequent periods of depression, he still continued to be busy and productive. He realized the importance of this dogged dedication when he remarked that there is a vast difference between casual flashes of intuition, and taking an idea seriously, working through all of its complexities, and winning universal acceptance for it.[41] Moreover, Freud believed in the importance of continuing to work even when ideas were not in abundance: when an idea did not come to him, he would now "go half-way to meet it."[42]

In one area of his life, Freud differed from nearly all other scientists before him. While most scientists can (and perhaps prefer to) keep their lives at arm's length, Freud's very scientific being came to rest on the facts and the feelings of his own life. Quite possibly the most significant and the most daring decision of his professional life was

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the initiation in 1897 of his self-analysis: the exercise, which he continued until the end of his life, of examining his deepest thoughts for clues about how the mind—particularly its least conscious processes—operated. Though it is most difficult to assess intrapersonal intelligence from the outside (only one's psychoanalyst knows for sure!), it seems reasonable to infer that Freud had a high degree of intrapersonal intelligence. Indeed, the distinctive coloring of his intellect comes from the blend of logical, linguistic, and personal intelligences. Moreover, Freud did not simply pursue the self-analysis for his own personal edification: he shared his hopes and fears, his embarrassments and his triumphs, his most profane wishes and most ardent secret hates, with his readers and his live audiences. Even when he may have wished to disguise these experiences somewhat, the fact that he was willing to publish his dreams left them as fair game for all succeeding analysts—a challenge that more than a few have taken up in the ensuing decades.

As a result of this baring of his soul, we have amassed considerable information about Freud's family life, his friends, and his professional enemies as well. Freud emerges as someone who identified strongly with his roots—with his parents, the rest of his family, his Jewish background—even as he was ultimately quite critical of most of his professional colleagues and of the duplicities and injustices meted out by the powerful Viennese society. Freud had a strong need to form alliances with individuals, an equally urgent need to define others as being in an out-group. For many years, he felt extremely isolated, particularly in light of the skepticism toward his theory expressed by most members of the Viennese scientific and medical establishments. At the same time, however, he profited from excellent teachers—the neuroanatomist Bruecke and the psychiatrist Charcot—who supported his professional endeavors during the first years of his career; and loyal friends, first Josef Breuer and then Wilhelm Fliess, who listened to his still inchoate ideas and supported him as best they could. Nor were these individuals "fringe characters": while Breuer was more conservative, and Fliess yet more radical than Freud, both were highly cultivated and successful physicians whose esteem must have meant a great deal to the struggling Freud.

Once psychoanalysis had been launched, Freud's interactions with others took on different dimensions. Now, instead of being the junior member of a relationship, he became the focal figure: the individual

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around whom other younger physicians were to gather. In retrospect, it is clear that Freud made many mistakes in the way in which he sought to promulgate his views and to organize his followers, and he paid dearly for these errors. His interpersonal intelligence, while ever active, was flawed and yet it seems apparent that psychoanalysis could not have achieved international success without Freud's considerable gifts of leadership and insight into one's fellow human beings.

This cursory sketch of Freud's capacities and life experiences as viewed from a psychological perspective reminds us of the multiplicity of factors that interact and contribute to the achievements of a single creative life. I have focused on cognitive and intellectual features but have touched on personality, social, and motivational effects as well. In a case study, it is of course impossible to determine *which* of these factors were truly essential, *which* could have been dispensed with, *which* might even have hindered Freud. The purpose of a psychological investigation of a single creative individual is to come up with the most plausible account of the roles played by various factors, and, most especially, to attempt to understand how various cognitive, personality, and social factors interacted at specific points in that life. Only when numerous case studies like this have been carried out does it become plausible to propose *models* of the creative psychologist, the creative natural scientist, or (should it prove apposite) the creative person in general.

The Domains of Freud's Contributions: Cognitive Representations and Artificial Intelligence

I have, until now, focused on the personal characteristics of Freud—his cognitive profile, his personality traits, his motivational structure, his relation to significant individuals in his personal and his professional life. It is possible, however, to examine Freud's work—his professional achievement—while excluding his personal contributions. In so doing, in studying Freud's contributions as if they had been achieved by someone else, one must shift one's focus to the *domain* of knowledge.

A study directed toward domains can proceed in one of two directions. On the one hand, there are the particular pre-existing domains of knowledge to which Freud made contributions, ranging from neuroanatomy to clinical psychiatry, from literary criticism to

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sociology. On the other, one can elect to focus instead on Freud's achievement as if it were (or as if it ultimately became) *itself* a domain. In this latter case, a domain study amounts to a series of portraits of Freud's own work as it passed through its various phases. In each case the interest lies not in a summary of what Freud did, but rather on the ways in which his lifework was creative—how it made a novel and substantive contribution to a body of knowledge or itself constituted a set of creative products.

To attempt a characterization of the numerous domains of Freud's work would far exceed the scope of this essay—indeed it is an effort that would require many volumes. My more modest purpose here is to indicate the tools of cognitive science that might be brought to bear on this enterprise.

The first task of a domain analysis would be to lay out the principal precepts and lines of knowledge that existed *prior to* Freud's involvement in a given domain of knowledge or practice. Since Freud contributed to approximately a dozen separate fields of scientific and cultural analysis, this represents a formidable undertaking. (Frank Sulloway's attempt to relate Freud's contributions to the evolutionary biology of his day absorbs several hundred pages.[43]) In each case, then, one would try to isolate the particular scholarly contributions made by Freud and to determine the ways in which the consequent field was affected (or remained unaffected) by his work. Naturally, experts in the history of each domain would need to be recruited for such an endeavor.

In Freud's case, the enterprise becomes yet more formidable, for Freud did not simply contribute to existing bodies of knowledge. In some cases, such as the psychology of personality, he radically reshaped the field. In others, such as the treatment of neurosis, it might equally well be said that he created an entirely new domain.

So far, the study of domains of knowledge has been approached principally from the point of view (and with the tools) of the historian of science. However, the same task can—and should—be approached as well by the scientist interested in cognitive representations. Here the task entails an effort to describe Freud's "mental models" as they existed, and as they changed, at crucial times during his scientific evolution. Such an endeavor would include microscopic examinations of particularly crucial intervals: for example, the frequent changes in Freud's conceptualizations during the work on

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the *Project for a Scientific Psychology* in 1895.[44] It would also include more macroscopic examinations: for instance, a tracing of the evolving conceptions of the ego, or of anxiety, over a period of several years. In addition, such an enterprise would involve a consideration of which aspects of Freud's scientific development exploit knowledge that had been obtained far earlier in his career, and which aspects were genuinely dependent upon new findings or insights obtained from reading or from clinical experience. Finally, and most crucially from a cognitive-scientific perspective, such an account would attempt to lay bare the principles or mechanisms by which one model came to be altered, transformed, or settled.[45]

It is legitimate to ask whether the field of cognitive science possesses special tools for such efforts. The answer must be tentative, for, as I have noted, few cognitive scientists have directed their attention to creative products of any scope. In Howard Gruber's pioneering investigation of the notebooks of Charles Darwin, however, we have available a useful model of how such a cognitive analysis might work.[46] What is needed, at one extreme, is the most fine-grained analysis of the degree of knowledge possessed, and the way it is organized, during every step of a creative scientific breakthrough. (This is what Gruber achieved in his examination of Darwin's notebooks during a crucial period in 1837–1839.) On the other extreme, and equally necessary, are more general concepts: for example, the images of wide scope, which guide an inquiry; the network of enterprise, which includes the various kinds of questions on which an engaged scientist finds himself working at any one time; the overall set of purposes that, as Gruber indicates, cause the scientist to adopt certain tacks, while spurning others.

While contemporary cognitive scientists do not have exclusive possession of any of these tools, their understanding of the structure of mental representations (schemas), rules of transformations, and limits on information processing capacities should facilitate a more systematic and testable analysis than was hitherto possible.[47] Moreover, it is so complex a task to keep track of the various schemas of knowledge possessed by *any* individual, let alone those constructed by the creative scientist, that only powerful computers have the potential to handle this task. Even casual consideration of the many different enterprises in which Freud worked over sixty years, and the hundreds of projects in which he became engaged and brought to

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some state of fruition, should underscore the need for computational aids in any comprehensive analysis of the file one might dub SIGFREUD.

Here lies an opportunity for artificial intelligence. A principal purpose of this new field is to devise clear models of cognitive processes and to determine whether these models are viable—whether they exhibit psychological plausibility.[48] We are still some distance from being able to model the understanding of a normal expert in a given domain, let alone the contributions of a creative genius in the process of founding a new domain. Yet, in principle, it should be possible to model the changing thought processes of an active scientist and to ascertain whether that model is in fact viable. If one can seek to model the mind of a paranoid (PARRY), or the processes of induction entailed in scientific work (BACON), why not attempt to model the mind of a creative scientist? Furthermore, if the modelling of a mind of a creative artist or scientist retains the quality of science-fiction, that is not the case for the modelling of individuals who are in the process of gaining knowledge about a new area. Individuals training to be psychoanalysts (or psychological theorists) pass through a sequence that can be well described as a novice-to-expert transition: modelling of such a passage is within the purview of contemporary artificial intelligence.

An approach via artificial intelligence has a further advantage. In considering the contributions of an individual such as Freud, who was in many ways an authentic hero, one is prone to become enwrapped in the mythology of psychoanalysis and to attribute more originality to his discoveries than may actually be warranted. Computational models allow one to examine the sources and the transformations of the ideas without any interference by knowledge of the personal circumstances surrounding the creation. If Frank Sulloway is correct, nearly all of Freud's major discoveries had been anticipated, in some cases by well-known predecessors like Charles Darwin or Richard von Krafft-Ebing, in others by his own intimates whom he did not adequately acknowledge, like Wilhelm Fliess or Alfred Adler. Doubtless one result of the "domain-study" espoused here would be to document the extent to which Freud stood on the shoulders of giants. His contribution is sufficiently singular that it will survive such dissection.

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A final question concerns the limits of the domain of "domain-study." Where does humanistic scholarship stop and cognitive science commence? The beginnings of an answer lie in the search for general patterns and for replicability. While a study of creative lives and products should, in my view, begin with a sophisticated understanding of particular instances, it must not end there. The cognitive scientist is on the lookout for principles and laws that pertain to groups of individuals, if not to all instances of creativity: the humanistic scholar does not have such generalizations as a major goal and indeed may be more interested in particularities and uniquenesses than in universals. Thus, in considering the above sketch of Freud, the cognitive scientist is not interested primarily in the particular set of intelligences, personality traits, or social factors that produced Freud, but rather in the ways in which intellectual, personality, and social factors coalesce, more generally, in order to produce unambiguous instances of creativity. By the same token, the erection of models is designed not merely to account for the contributions of one individual—no matter how epochal—but rather to understand altogether the nature of creative enterprises as they unfold in science, art, and other spheres of human activity.

The Field of Freud: The Historical-Cultural Context

The "genetic Freud" could have lived anywhere on the planet, but the "historical Freud" spent most of his life in Vienna. Around the turn of the century, Vienna was in many ways unique, and it is appropriate to assume that this cultural "field" exerted an important, if not decisive, impact on Freud's lines of development.[49]

On the surface, Vienna appeared to be a stable and powerful site, the capital of the spacious and long-lived Austro-Hungarian empire. Ruled by Emperor Franz Joseph from 1848–1916, it seemed to represent solid Catholic values that were shared by aristocrats as well as leading members of the bourgeoisie. As a center of learning, Vienna had few peers, and as a medical center, it was arguably the best in the world. A liberal minority occasionally occupied positions of influence, but in general the community embraced reactionary positions and spurned novel political ideas. Curiously, however, there was a guarded tolerance rather than ruthless repression of innovative ideas in the arts and sciences.

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It is in this peculiar tension between political and social conservatism, on the one hand, balanced by tacit support for the exploration of new ideas in arts and sciences on the other, that the special genius of *fin-de-siècle* Vienna lay. Those involved in these speculative areas formed a small but influential group, which was essentially cosmopolitan and supranational rather than narrowly Viennese or Austro-Hungarian. In a way that is difficult for us to appreciate, disciplinary specialization was scarcely known. Whatever their major professional identifications, Viennese intellectuals were exposed to a wide range of ideas, and most leading figures were familiar with the currents in disparate domains. Moreover, these individuals frequently entered one another's spheres of activity. To take just a few examples, composer Anton Bruckner taught piano to physicist Ludwig Boltzmann; composer Gustav Mahler brought his psychological problems to Freud; Freud's colleague Josef Breuer was the physician of philosopher Franz Brentano; the home of philosopher Ludwig Wittgenstein was a center of discussion in areas ranging from music to psychology.[50]

Finding themselves at the cutting edge of their own fields, yet in touch with the gamut of disciplines, living in a seat of power but within a community that was somewhat marginal, wrestling with the tension between conservatism and tolerance, brilliant young Viennese were in a privileged position to rethink the basic assumptions of their chosen domains. That is what they did, in domain after domain, between 1880 and 1920. Cherished Enlightenment ideals like the belief in progress, reason, and order; entrenched assumptions like the need for disciplined conformity; aesthetic norms like musical tonality, visual realism, and literary conventions; articles of faith like the Kantian conception of space and time—all of these and many more were challenged by the best minds of the time. There was a widespread desire to cut oneself off from historical precedents, to open oneself to hitherto mysterious psychic states, to locate or forge key conceptions that would set the tone during the unknown century ahead.

Sigmund Freud was as sensitive to, and as much an instrument of, these features as any of his contemporaries. Indeed, trained in the sciences, but working in areas close to the humanities, he was especially alert to the collapsing of norms and the undermining of shibboleths everywhere. Politically liberal in a conservative epoch, a

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Jew in an environment where anti-Semitism was rife (if not always overt), a champion of sexual candor in an environment that suppressed all mention of sexual themes, Freud felt the tensions acutely. He often spoke critically of the Viennese surroundings and, as a practical matter, he avoided "high society" of any sort and remained within his small and almost entirely Jewish circle. Yet, it can be argued that Freud had a symbiotically productive relationship with his home territory: living elsewhere, he might not have had the opportunity to make many of the observations that were key to his theory. Nor would he have felt that intense struggle between the expression of human instincts and the dictates of a repressive society which ultimately animated his theoretical edifice.

One cannot perform the crucial experiment and move Freud to another location anymore than one can exchange Ludwig Wittgenstein with Jean-Paul Sartre, Arnold Schoenberg with Charles Ives, or Gustav Klimt with Aubrey Beardsley. Yet the incredible flowering of talent in Vienna during a relatively brief band of time is powerful evidence that the particular atmosphere *was* conducive to creativity—even as Florence in the Renaissance or China during the T'ang dynasty was similarly catalytic. Perhaps the best evidence for this massive "field effect" lies in the poignant fate of Vienna in the latter period of Freud's life. Franz Joseph died in 1916, the Hapsburg house did not survive the end of World War I, and Vienna as a major intellectual community did not outlast the rise of Hitler. Indeed, it could be argued that there has not been a single figure in the post–World-War-II era in Vienna to match the dozens of luminaries who frequented the coffee-houses in Freud's time.

Cultural-historical studies connect human cognition to the environment or field in which it is nourished, where it is redirected or thwarted. No matter when or where one lives, an individual confronts a domain of knowledge within particular fields, ranging from the intimate family circles where education begins, to the larger institutions of society in which one ultimately circulates. Placing Freud at the center, one can draw concentric circles extending outward, and including in turn his early family and school environments, the university and medical schools, the post-university training in France as well as Vienna, the laboratories and clinics where his crucial observations were made, the lecture halls and journals where his ideas were first tried out in public, the columns of newspapers in

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Vienna where they were sometimes ridiculed, his first group of intimate followers who met on Wednesday evenings in his home, and, eventually, his ever-expanding circle of students, peers, friends, admirers, and detractors all over the world, beginning in the 1910s and extending even until today.

Again, these issues have routinely been considered the domain of biographers and historians. The anthropologist or historian of science with a cognitive-scientific slant will adopt a comparative approach: a contrast of Vienna with other cities, of Freud's circle with other circles, of progress in a field like psychology with comparable progress in physics, poetry, or pottery. He will be animated by a search for general principles and will attempt to model the ways in which any cultural field affects the nature and transformation of cognitive representations. Of special interest will be those rare communities, institutions, or situations where creativity seems to flower—which may range from several generations of artists in Florence to the graduates of a particular high school in Budapest or the Bronx. By the same token, it will be of interest to carry out studies of communities or schools where high creativity *might* have been anticipated but where, for reasons as yet undetermined, there were few if any creative individuals or creative products. Possibly there may be mechanisms that minimize the effects of the field upon the individual, with an autistic individual representing an extreme causality.

Biological Foundations of Creativity

Even as cultural studies of the "field" define the upper bound for a study of creativity, the biological and neurological disciplines mark the lower bound. (Analyses at the level of atomic particles are simply irrelevant.) Logically, in fact, a cognitive-scientific account of creativity ought to begin with a consideration of these biological factors, for they are preliminary to any behavior whatsoever.

I have deliberately postponed a consideration of these factors, however, for two related reasons: first, very little is known at this time about the biological facets of creativity; second, the desire to analyze the biological basis of creativity and giftedness has been a controversial issue, partly for good reasons.

Let me consider the controversy first. For many years, psychologists preferred to adopt a "black-box" approach to mental phenom-

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ena. The desire to avoid biology reflected the need to establish autonomy for the field, lest it remain forever parasitic upon the "wet" sciences. Added to this disciplinary chauvinism has been a second factor. In many eyes, the search for a biological basis for, say, intelligence or talent has been collapsed with a desire to establish that these factors are innate or predetermined—and hence, with a justification of the *status quo*. Indeed, while biological workers of every stripe have at one or another time directed their attention to such psychological issues, there has been a tendency on the part of these workers to be skeptical about the significance of environmental contributions to unusual promise or unusual performance.

Neither of these reasons, however, suffices to preclude a genetic or neurobiological approach to issues of creativity. First of all, cognitive studies have established the legitimacy of an analysis on the level of mental representation. The likelihood of its being engulfed by a reductionist approach seems remote.[51] As for the sometime equation of biological with predeterminist or nativist analyses, this is a contingent, not a necessary state of affairs. For that very reason, individuals pursuing a neurobiological analysis of creativity or giftedness ought to be especially vigilant that their findings not be uncritically absorbed into such a framework, with its rich potential for abuse.

Still, it seems clear that the tools and insights of the biological sciences ought to be brought to bear upon important facets of human thought and behavior—certainly including the area of creativity. Indeed, just because of the many path-opening findings in biology in the past decades, it is high time to reopen the issue of the biological bases of creative behavior. In this spirit, my colleagues and I have recently convened a conference on the topic of the biology of giftedness,[52] and I have also explored dimensions of this subject in occasional writings.[53]

One can readily discern areas of biology that might prove relevant to a study of creativity. Any such accounting would certainly include studies of the genetics of unusual abilities and unusual performances; the relevance of animal models and experiments to unusual human performance; the development of the nervous system in early life and the way in which it comes to be organized in normal and exceptional individuals; the relationship between patterns of cerebral lateralization, neuroanatomical structures, and exceptional capacities; the

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processes of cerebral blood flow in unusual individuals as they are engaged in solving challenging problems or creating novel products; patterns of precocity and aging in individuals with different cognitive profiles; measures of the hormonal and neurochemical patterns of individuals engaged in highly creative activity; studies of energy, drive, and sleep cycles in creative individuals; and dozens of other equally pertinent indices.

What proves much more difficult, however, is to institute such lines of research and to determine the ways in which they might genuinely illuminate specific creative individuals and behaviors. Our own surveys have indicated that neurobiological and genetic studies have advanced most rapidly when dealing with systems that are relatively simple and that unfold over a brief span of time. As envisaged in these pages, however, creativity involves systems of great complexity that unfold over extensive periods of time. Neurobiology is as ill-prepared as cognitive psychology for dealing with these macroscopic phenomena. As a result, neurobiological investigations can have nothing to say about Sigmund Freud's agenda or his achievement.

An equally formidable problem surrounds the issue of individual differences. Until now, studies of individual differences have assumed little import in the neurobiological sciences—universal or species—and specific behaviors have (understandably) been at a premium. Indeed, most studies on the aforementioned topics focus on the species as a whole, or on the grossest of individual differences, such as gender or handedness. Yet, as stressed throughout this paper, creativity must be studied in the *individual* who is creative. Ultimately, then, neurobiologists will need to consider the ways in which particular individuals, and individuals in particular situations, may differ from their peers. Since we do not know *whether* they will differ—let alone in which ways they may differ—a considerable scientific gamble is entailed. Even if we were to have Einstein's or Freud's brain completely at our disposal, it is not clear where we should look, what we should count, and how we should interpret our findings.

Still, I have little doubt that the speculative leap is worth taking. Just as the mind in its many facets stands as the major "general" target for current neurobiological work, creative efforts are among the most important "specifics" in need of elucidation. Numerous tools have been evolved over the past few years that facilitate studies

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of individual differences. There also exists within the biological sciences ample precedence for dealing with processes that take place over long periods of time—whether it be studies across the life span or investigations extending over millions of years.

One other point worth stressing is that neurobiologists can now expect to receive aid from researchers working at the other side of the cognitive-scientific interface. Many psychologists and artificial intelligence researchers working at the level of "domain" or "intelligence" are now probing cognitive processes in great detail: an account in terms of underlying neurophysiological or neurochemical processes is no longer remote. When it comes to the study of particular human faculties, ranging from language to vision, there is again a cadre of workers prepared to see their work analyzed in terms of underlying biological systems. Such common interest is no guarantor of success, of course, but it makes initial collaborative efforts more tenable.

Concluding Remarks

Rather than reporting the results of a particular research program, this essay envisions a possible scientific future. We know very little about creative individuals or creative works in any domain; as I have suggested, much of what passes for knowledge is probably not relevant to an understanding of unambiguous instances of human creativity. My faith, which I have articulated here, is that a cooperative cognitive-scientific effort to illuminate creativity is becoming a possibility. One can begin by examining the three levels of description—intelligences, domains, and fields—from the perspective of the several appropriate disciplines. In my view, few challenges should be more attractive to a unified cognitive science than a newly animated attack on the problem of human creativity.

I wish to touch on a number of topics that may not fall strictly within the purview of a cognitive approach but that ought to be broached in any extended discussion of creativity. One issue involves the relation between creative activity and mental health. In the literature on creativity one can encounter the full gamut of views on this topic: ranging from the belief that creative individuals realize the healthiest of existences, to a conviction that creativity and neurosis (if not psychosis) are closely allied. Indeed, any number of instances supporting these apparently contradictory contentions can be adduced.[54]

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My own belief is that creative activities produce a peculiar vulnerability in individuals: the two extremes just outlined are both (if not equal) possibilities. In the case of Freud, one finds considerable evidence that he was a generally healthy individual, physically as well as mentally, and that his personal and family life were, to speak anachronistically, quite "together." Indeed, it has even been argued that his neurosis was a "creative illness" which helped to bring about his great discoveries.[55] Yet, it is clear that he was subjected to severe (if transient) depressions at times when he was particularly vulnerable to criticism and to the fear that he may be engaged in worthless pursuits.[56] It must also be said that there are costs to membership in the life circle of a creative individual. Numerous individuals who interacted with Freud felt his formidable presence and ultimately suffered when he turned against them. In a few cases, suicides could be related to prior painful interactions with Freud.

The wider point is that the stakes are high in creative activity, and the results not always beneficent. Extended study of the relations between creative lives and health is indicated and cognitive science ought to contribute to that effort.

A second facet entails the moral dimensions of creativity. There is a tendency to equate creativity with positive contributions, and yet a moment's reflection reveals that there is nothing inherently moral or constructive about a creative individual or product: Adolf Hitler wandered the same city streets as Sigmund Freud, admired some of the same buildings, musical works, and individuals as did Freud's contemporaries, and began to hatch some of his diabolical plans during his *Wanderjahren* in Vienna.

It may be a mistake to couple issues of creativity with issues of morality, particularly since so many creative individuals have apparently been unconcerned with such issues and many others have led lives and espoused values that few today would admire. Still, I believe that a study of creativity ought to have a moral dimension. First, I think it is important to consider the moral stances taken by creative individuals—or, in selected cases, to consider why moral issues were *not* considered part of an individual's personal or professional agenda. One wonders, for instance, why Einstein (who worked in an area remote from human affairs) was drawn deeply into the politics of his era, while Freud (deeply immersed in human investigations) generally spurned topical debates (except when he could

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converse with the likes of Einstein!). Second, and more controversial is my belief that those of us who elect to study creative processes assume a special burden with respect to the knowledge that we acquire. Just because creative individuals are likely to have a disproportionate impact on the circles in which they live—be it limited to their friends or extended to the larger society—it is important to understand how these effects are wrought and how they might be channelled to the advantage of human society.

In arguing that students of creativity ought to ponder the moral implications of their findings, I am under no illusion that we have any special insights to offer. Indeed, one may well question whether *any* individuals have special insights in this area. Yet just because these individuals and these issues are so crucial for human survival and for human thriving, I think it is important for us to make public our findings and to discuss what the moral implications of our findings *might* be. No doubt, subsequent discussion will reveal which ideas or implications (if any) are worth pursuing.

I return finally to the realm of science, and, in particular, to the scientific status of the framework proposed here. It should be obvious that my remarks here are in no sense a scientific theory: there are no laws or principles that lend themselves to empirical testing, nor even a set of propositions that can be evaluated on the plane of logic. What I have put forth is more properly considered a framework for organizing and synthesizing findings with the aim of illuminating important, but as yet largely elusive, phenomena.

At the same time, I would be disheartened were these ideas discarded as irrelevant to scientific practice. I hope to have made the case for attending to certain large-scale phenomena that are easily overlooked in the pursuit of "normal science." I hope as well to have suggested, through some remarks about one creative individual, how the framework might some day illuminate instances of creativity and perhaps even lead to laws that have some scientific permanence. Whether these *laws* will govern all instances of creativity, or whether scientific creativity will emerge as distinctly different from, say, artistic or political creativity must await further study, though I would hope that the present framework could be adopted to several lines of investigation.

Moreover, and perhaps of greater scientific importance, there are many lines of work ongoing in the cognitive sciences today, which

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could readily and appropriately be redirected so that they pertain more directly to creative phenomena. The list would range from studies of brainwave activity in subjects with particular combinations of talents to studies of friendship patterns among children with contrasting cognitive profiles. One assignment for the student of creativity is to aid in this process of redirection. A second task is to turn particular attention to the ways in which findings at the intersection of two or more disciplines may relate to and inform one another; and ultimately, to attempt to piece together findings from disparate sciences that may jointly help to illuminate creativity. This is not a task at which we, as scientists, have much experience, though it is a task at which some great scientists (like Darwin and Freud) have excelled. The synthesizing genius that characterized the most creative individuals of the past must be brought to bear, if we are to secure a comprehensive account of creativity.

ENDNOTES

[1]For standard reviews of this empirical literature on creativity, see David Perkins, *The Mind's Best Work* (Cambridge, MA: Harvard University Press, 1981); Albert Rothenberg and Carl Hausman, eds., *The Creative Question* (Durham, NC: Duke University Press, 1977); E. Paul Torrance, *Rewarding Creative Behavior* (Englewood Cliffs, NJ: Prentice Hall, 1965); Philip Vernon, ed., *Creativity* (London: Penguin Books, 1970).

[2]Howard Gruber, *Darwin on Man* (Chicago, IL: University of Chicago Press, 1981).

[3]David Feldman, *Nature's Gambit* (New York: Basic Books, 1986).

[4]Examples can be found in Torrance, *Rewarding Creative Behavior.*

[5]Jerry Fodor, *The Modularity of Mind* (Cambridge, MA: MIT Press, 1983); Howard Gardner, *Frames of Mind* (New York: Basic Books, 1983) and *The Mind's New Science* (New York: Basic Books, 1985).

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[7]David Feldman, *Beyond Universals in Cognitive Development* (Norwood, NJ: Ablex, 1980) and Feldman, *Nature's Gambit.*

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[15]Ernest Jones, *The Life and Work of Sigmund Freud,* edited and abridged by Lionel Trilling and Steven Marcus, (New York: Basic Books, 1961).
[16]Ibid., p. 17.
[17]Ibid., p. 16.
[18]Ibid., p. 38.
[19]Ibid., p. 161.
[20]Ibid., p. 223.
[21]John Gedo, *Portraits of the Artist* (New York: Guilford, 1983).
[22]Jones, *The Life and Work of Sigmund Freud,* p. 37.
[23]Ibid., p. 344.
[24]Ibid., p. xi.
[25]Ibid., p. 26.
[26]Ibid., p. 366.
[27]Ibid., p. 23.
[28]Ibid., p. 19.
[29]Ibid., p. 19.
[30]Ibid., p. 131.
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[32]Jones, *The Life and Work of Sigmund Freud,* p. 66.
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[37]Jones, *The Life and Work of Sigmund Freud,* p. 227.
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Daniel C. Dennett

Information, Technology, and the Virtues of Ignorance

WHEN I WAS ABOUT TEN YEARS OLD, I read *Robinson Crusoe* for the first time and could scarcely contain my delight with the ingenious and resourceful ways Crusoe transformed his island world, bending its inventory to his own purposes, surrounding himself with contrivances of his own design and manufacture for enhancing his powers, and providing for his safety, nourishment, and pleasure. I discovered right then that I was in love with technology, as no doubt many of you are. We should recognize—we technophiles—that our love affair with technology, like all good love affairs, is not entirely rational, try as we may to rationalize our devotions. Crusoe the technocrat—it is one of the great fantasy themes, right up there with sexual adventure, athletic triumph, being able to fly, being invisible. It rivals them all in its captivation, in the luxuriousness of its details in our minds' eyes. It is far more satisfying than magic, precisely because it is *not* magic; it is something *we create,* and hence are presumably responsible for; it is something we *understand,* presumably, and hence, presumably, control.

We live today in a wonderful world in which the fantasy of unlimited technological enhancement seems to be coming true. This is convenient for us technophiles, for we can point to the many blessings our loved one has provided for us all—even the ingrates. Which technophobe would choose to live the harrowing and desperate life of the medieval peasant or the Stone Age hunter? Yet, like Crusoe, we pay some price for whatever we gain, requiring some

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minor revision in our habits, some curtailing of our options, some petty irritations that crop up as side effects with the adoption of each new marvel. Some find it easy to push these slightly nagging debits into the background; they say "Yes, there are costs of course, but it's not worth our while trying to sum them—whatever they come to, they are a small price to pay for the obvious gains." Others find their uneasiness harder to quell; they wonder if, when the total costs of some of the more indirect effects of new technology are rendered, we may not find that we have moved imperceptibly into a world we do not know how to inhabit and cannot leave.

I propose to focus attention on certain troubling aspects of this relationship between technology and morality.[1] I wish to consider the possibility that information technology, which has been a great boon in the past, is today poised to *ruin our lives*—unless we are able to think up some fairly radical departures from the traditions that have so far sustained us.

We all want to lead good lives—in at least two senses. We want to lead lives that are interesting, exciting, fulfilling, and happy, and we want to lead lives that are morally good as well: we would like to be useful, and to make a difference—a difference in the right direction, whatever direction that is. There is no doubt that technology in the past has facilitated both these aspirations, freeing us from drudgery and misery, making it possible for many of us to improve the lives of others. But unless we can find solutions to certain problems, the curve will turn. We have reached a point where the advance of technology makes the *joint realization* of these two goals less likely—we may have to make an unpalatable choice between lives that are morally good, and lives that are interesting.

Since my message is one that many may find unpalatable, it may be useful for me to start with a very specific instance of the trend that concerns me, before drawing on it for wider implications. As technology imposes new sources of knowledge, it renders obsolete the standards that guided our individual actions in the past. Consider, for example, the case of the rural doctor. Today, there are doctors who have chosen, commendably, to forsake lucrative urban or suburban practices for more valuable and meaningful lives as doctors in small rural communities. Their virtues have often been sung;[2] there is little need for me to dwell on them. These doctors know their patients well; their personal, intricate, involved knowledge stands

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them in good stead when they come to diagnose, treat, and advise the members of their communities.

Such doctors, for better or worse, are an endangered species. Technology is on the verge of rendering their style of medical treatment obsolete, and—because of its obsolescence—morally indefensible. As expert systems for medical diagnosis become available, these doctors will have to decide whether to avail themselves of the new technology. Let us suppose, for the sake of argument, that the systems will work as well as their supporters claim; they really will provide swift, reliable, and accurate diagnoses of ailments across the wide spectrum of medical cases the average physician is likely to encounter.

If so, the doctors, in good conscience, will have no choice: they will have to avail themselves of the new expert systems. To choose not to equip themselves with the best available means of securing accurate diagnosis would be a gross dereliction of duty, just as if—for some romantic whim—they chose to deny themselves use of a telephone, or insisted on making their rounds on horseback, or refused to consult x-rays before operating. Quaintness is acceptable when matters of life and death are not at stake; but few would be enthusiastic about a doctor who insisted on relying on old-fashioned methods, particularly if it entailed a serious and avoidable risk of misdiagnosis or mistreatment.

Doctors have always been obliged to keep up-to-date with their medicine, and typically have responded to this obligation with fairly serious efforts to stay abreast of medical journals, to take refresher courses. The generation of information has recently been getting out of hand; until now, rural doctors have been excused from knowing everything that their urban colleagues were held responsible for—there are limits to what people can be expected to carry around in their heads.

Now, however, a technology is promised that will render such limits obsolete. All you will have to do is install a modem and a cellular telephone in your four-wheel-drive van and there, at your fingertips, will be a credible approximation of the finest corps of specialist consultants, available twenty-four hours a day. You would have to take a curious moral stand indeed to resist becoming reliant on such a system. How dare you turn your back on such a fine new source of information, when lives—lives entrusted to you—depend

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on you making the best informed diagnoses of which you are capable?

The standards of excusable ignorance for even the most isolated of rural doctors will shift, and the doctors will be required to alter their practices to meet wholly new standards. All doctors will be expected to avail themselves of the new technology, just as all doctors now are required to maintain standards of antiseptic practice. We may suppose that expert systems will enable doctors to practice much better medicine, but in order to use these systems they will have to relinquish some practices they may well have prized in their earlier *modus operandi.*

At present, rural doctors can take a varied, even informal, approach to gathering facts about their patients. If old Sam looks OK, sounds just about the way he always sounds at this time of year, and does not complain about anything new, the doctor can leave well enough alone. Besides, if there really is anything new wrong with old Sam, it is too esoteric, or too obscure at this stage, for the rural doctor to be expected to diagnose it. After all, rural medicine is not the Massachusetts General Hospital. But expert systems will change all this. Doctors will be obliged to ask all their patients a battery of questions they never felt the need to ask before—for what use could they have made of the answers?

They will also be obliged to perform a variety of largely simple tests they never felt bound to perform before. They will do so because the feeding of expert systems with such data will supposedly have proven to bear valuable results—permitting a higher rate of early diagnosis of treatable cancer, for instance. Gathering information by these two methods—asking questions and performing simple tests—will be made as easy, straightforward, unequivocal as possible. Indeed, the procedure will be *as routine as possible,* for the more routine it is, the more uniform the feeding of the expert systems will be, and hence the less likelihood there will be of misinforming them.

In this way, the "art" of diagnosis, and the "art" of "taking a patient's history" will be reduced, as far as possible, to an exercise in which the art is displaced by the mere capacity to follow directions. I am not claiming that such systems would place a positive value on the deliberate suppression of imaginative, artful investigation and diagnosis, but just that such activities would be relegated to whatever

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room remained *after* the doctors had done their duty by asking all the *obligatory* questions and performing all the *obligatory* tests.

Since "progress" in medicine (and technology generally) proceeds by replacing art with obligatory practices whenever the principles governing the art can be well enough understood and justified to be codified, we can expect that, insofar as the technology of medical diagnosis succeeds, insofar as it becomes so demonstrably reliable that doctors will be obliged to use it, it will do so by diminishing the regular, daily contribution of the medical practitioners who use it. Once in a while, the artful doctor may find a moment in which to exercise his or her art, and even save a life by filling a gap in the technology, but such opportunities will become rarer as the technology improves.

A subspecies of doctor will thus become extinct, succeeded by a new species that will delegate more and more diagnostic responsibility to expert systems, not because of their indolence or stupidity, but simply because they will not be able to defend the claim that they can do as well or better without the systems.

Should we mourn the passing of this species of practitioner? If we adopt the doctors' own point of view, we can see why they might well regret this development: it will make their own lives less exciting, less indispensable; they will begin to sink into the role of mere go-betweens, living interfaces between patient and system, who consolidate their direct observations into machine-readable symptomatology, and execute the therapeutic directives of the system.

It may help us to conceive of their predicament if we imagine their secret yearnings: they will occasionally be tempted to "live dangerously," to "fly by the seat of their pants," to take risks with their patients' lives just to prove to themselves that they still have the "right stuff"—that they can make bare-handed diagnoses as well as the best of the old-time doctors, the swashbuckling specialists of the 1970s and '80s. The more adventurous (or self-indulgent) of them may seek out the few exotic environments where they can practice medicine free from the obligation to use the boring technology—much the way some like to "rough it" by going camping, or by sailing small boats across the ocean. Yet, thanks to communication satellites, even Robinson Crusoe's island will provide no asylum for the physician who seeks refuge from expert systems. Being a doctor simply won't be anywhere near as much fun in the future.

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This extinction of social roles is a familiar process in history. Artists, calligraphers, potters, and tailors used to be more indispensable to their communities than they are now. Although there still is a role for such artists, it is a luxury role; some people are willing to pay extra for that special, personal, artistic touch—but the realm in which the hand-made is superior to the machine-made has shrunk to an almost purely ceremonial, even mystical remnant of its former status.

Fortunately for potters, there are still enough people who prize hand-made pottery so that it is possible to sustain a career as a potter, but the social position of the potter has been ineluctably damaged; potters are simply no longer indispensable as they once were. While being a potter is still a good life compared with most others—it has more than its share of satisfactions and delights—it is not as fulfilling a life as it used to be, since any reflective potter must recognize that he or she survives by gratifying the desires of a rarified subset of the population. Doctors will not even be that lucky, for who in his right mind would acquire a taste for funky, hand-made medical care—just like Grandma used to get?

No doubt the rich and foolish would recognize a certain *cachet* in keeping a personal—and personable—physician in their entourage. Compare the doctor of the future with the apartment doorman. This descendant of the *concierge,* who had a relatively challenging and varied life work, has an almost purely ceremonial function today. You can telephone for a taxi with greater ease than your obliging doorman can lure one to the door, and the security he provides is typically almost redundant, given the twenty-four-hour surveillance and alarm system. But it looks nice to have a doorman. He adds a personal touch—of sorts. It is posh to live somewhere that is so well-heeled that it can afford to pay a grown human being to stand around in a uniform smiling all day. The doorman's life is not pleasant to contemplate; it is a travesty of human service, however well reimbursed.

Every doctor must begin to worry that he or she is heading towards becoming a health-care doorman. Can it be that, in a future generation, all that will be left of today's doctor will be minimal "computer literacy" and a bedside manner?

The advocates of expert systems in medicine may wish to intervene here, pointing out that, far from diminishing the life of the physician, expert systems will enhance it. The physician will have *more* time to

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deal personally with patients, and can care effectively for greater numbers, because the drudgery and galling uncertainty of poring through textbooks and journals for snatches of half-remembered wisdom will be eliminated. Indeed, and today's apartment doorman can "deal personally" with ten times as many inhabitants as the old-fashioned concierge, since all the drudgery has been removed from his life as well. The doorman has certainly been relieved of such menial labor, but also of responsibility, variety of challenge, and autonomy. Like the Cheshire cat, all that is left is the smile. As the responsibility for diagnosis and treatment shifts imperceptibly away from the physician—the "field operative"—and lodges in the expert system (or system of expert systems), doctors will suffer a similar, if less drastic, diminution of role.

I am not for one minute maintaining that today's rural doctors are heroes, and that their sad fate is the result of evil, rapacious technocrats seducing them from their noble lives. Greed and evil intentions do not enter this equation—though they are not in short supply. It is precisely because doctors want to practice the best medicine they can that they will find it incumbent on them to make these choices; for they will see that they will actually be able to save lives more reliably and efficiently by availing themselves of the technology. The interesting and risky life they had been leading will no longer be morally defensible. Wanting to be responsible and to do good, they will have to settle for a less exciting service role. We may suppose equally pure and altruistic motives on the part of those who design, develop, and promote the technology. They do not *intend* to spoil career opportunities; it is simply one of the foreseeable side effects of their effort to do a better job of saving lives through technology. What I am referring to is not a cheap melodrama with a convenient villain at which I can shake my finger, but more in the nature of a tragedy.

In a tragedy, the hero's ultimate fate must be seen to be inevitable; that is one reason why I hesitate to call this a tragedy. If I thought that this unhappy *dénouement* were strictly inevitable, I would perhaps have decided to keep the grim news to myself. How, then, might some alternative future await the physicians?

First, the technology of expert systems may turn out not to work all that well. We may discover that expert systems are so limited and unreliable, taken by themselves, that doctors will still have to be very

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self-reliant, very knowledgeable individually, very artful in the use they make of technology. Perhaps they will not even be obliged to use it, so untrustworthy will it prove to be. (In several conversations with advocates of such technology I have been amused to be assured, most solemnly, that I have vastly overestimated the actual powers of expert systems. These spokespeople for expert systems have failed to see the irony in their protestations: "Don't worry!" they say. "These expert systems aren't going to be *reliable!*—they won't be *foolproof!* Why, in the hands of an unskilled practitioner they would be positively dangerous!" I am strongly inclined to agree, but to suggest that to them would be to risk being dismissed as a technology-hating humanist.)

We have found one escape route: this particular technology will not work after all, and hence will not be obligatory, and hence will not spread to destroy this enviable and admirable variety of human life. There are several other ways out. If one thought that the technology *might* work, and thought that preserving the way of life of today's physician was of prime importance, one could take steps to avert this future: either by the Luddite tactic of destroying expert systems as they appeared; or by attempting to prohibit or prevent the development and improvement of the technology in the first place. But Luddism has never worked well in the past. It tends to postpone crises and aggravate situations, and is in any event not likely to inspire those who would have to support the policy today.

Alternatively, it may turn out that I have overestimated the physicians' commitment to practicing the best medicine they can. According to several observers, many doctors have given the new expert systems a lukewarm reception largely because they are more interested in "talking shop" with consultants, and in spreading liability, than in obtaining diagnostic assistance. If such resistance is widespread, it may prevent the public from perceiving the value of expert systems, and thereby keep the obligation to use them at bay.

Finally, of course, one could decide that saving the role of the *mid-twentieth-century physician* was, in the end, no more defensible than saving the role of the linotype operator in the production of newspapers. These roles must pass, perhaps, and as long as we ease the plight of the current holders of the positions, and prevent the recruitment of a new generation, little harm will be done to specific

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individuals. People in the future will just have other, no doubt better, occupations.

While that sentiment has a certain plausibility when the displaced workers are miners, linotype operators, or secretaries, it is far from clear what exalted work will remain for displaced physicians. If a social role as obviously valuable and impressive as that of the physician is in jeopardy, what future awaits the rest of us?[3]

Let us review the situation: if expert systems in medicine live up to their promise, then the tradition and the current trajectory of development suggest that they will probably ruin one of the most exciting and fulfilling careers in modern life. Without destroying it, they will diminish it enormously; people who want to live a good life—not just do good in life—will think twice before entering this part of the service sector. Perhaps the role of physician is not worth preserving. Alternatively, perhaps expert systems will not prove all that powerful, so that physicians will not be obliged to cede their responsibility to them. Or, in the hope that expert systems will fail to establish themselves, we might even take steps, violent or legislative, to forestall their deployment.

I see two further possibilities. The first and most probable outcome is that we shall be faced with the worst of both worlds: expert systems will not work anywhere near well enough for physicians to be *obliged* to rely on them, but the physicians will come to depend on them anyway, succumbing to the pressure of over-optimistic public opinion, their lack of self-confidence, and even laziness, greed, and fear of malpractice suits. A second somewhat utopian possibility is certainly worth striving for: perhaps we can design computer systems to support only the wily and self-reliant physician. We should look for design principles that would lead to the creation of systems that preserve or (better yet) enhance the contribution of the individual physician, while not sacrificing diagnostic power. I do not think that creating such systems is impossible, but it will not be easy; it will require rethinking the basic design task.

Compare expert systems to musical instruments: today's expert systems are similar to autoharps, designed so that anyone can learn to play them, and with an easily reached plateau of skill. We should aim instead to develop systems more like violins and pianos—instruments that indefinitely extend and challenge the powers of the individual.

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I have some inklings about how this might be accomplished. They stem from ideas I have been developing at Tufts' Curricular Software Studio with my colleague, George Smith.[4] We are creating several different kinds of "concept pianos" for the exploration of complex phenomena—such as population genetics and the computer's own internal architecture. If our ideas survive their current testing, we shall subsequently present them as steps towards a new design philosophy for expert systems, but in the meanwhile there is still plenty of philosophical work to be done on these issues, to which I shall devote my remaining observations.

Why should doctors find themselves riding this obligation-train to tedium? To understand this particular phenomenon, we must step back and take a more general view of the relations between information technology and our ethical lives as decision-making agents.

Our ancestors were, relative to us, epistemically impoverished: there were few means of finding out much about non-local, non-immediate effects and problems, so they could plan and act with a clear conscience on the basis of a more limited, manageable stock of local knowledge. They were thus *capable* of living lives of virtue—of a virtue that *depended on* unavoidable ignorance. Modern technology has robbed us of the sorts of virtue that depend on such ignorance, for ignorance is all too avoidable today. Information technology has multiplied our *opportunities to know,* and our traditional ethical doctrines overwhelm us by turning these opportunities into newfound *obligations to know.*

We have always had "principles of excusable ignorance." According to tradition, we are responsible for knowing whatever is "common knowledge," plus whatever is the received wisdom of those who occupy our specialized social role—such as the role of physician—plus whatever is obviously and directly relevant to our particular circumstances of the moment. We are all responsible for knowing the standardly understood relationships between smoke and fire, rainstorms and slippery roads, voting and democracy. Plumbers—but only plumbers—have been responsible for knowing the particular effects, opportunities, and hazards of the plumbing trade, and everyone is responsible for knowing whether anyone is standing behind one's car before backing out of a parking place.

The rough-hewn boundaries of these classes of knowledge were fixed by default by the limitations of human capacity. One could not

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be expected to carry around vast quantities of information in one's head, nor to calculate, in the time available, any of the longer-range effects of action. The example of the physician showed in some detail how technology interacts with the obligation to know in a specialized field, but its effects on "common knowledge" are even more severe and imponderable.

"Common knowledge" is no longer the relatively stable, inertial mass it once was. We *can* acquire knowledge with little effort on almost any topic; when knowledge is "at your fingertips," how can you not be responsible for acquiring it? The obligation to know—a burden of guilt that weighs heavily on every academic, but that in milder forms is ubiquitous today—creates the situation where, if we read everything we "ought" to read, we would have time to do nothing else. Thanks to science and mass communication, we *all* now know that, in addition to worrying about whether someone is standing behind our car when we back up, we also have to wonder about the effects of our personal auto-driving (and auto-buying) activities on air pollution, acid rain, the local and global economy, and so forth.[5]

The well-known glut of information has inspired a host of responses from those who must cope with it, or wish to exploit it. Since everyone knows that no one can possibly keep abreast of all this information, meta-techniques, meta-strategies, meta-meta-structures, meta-meta-meta-tactics have arisen. The "common knowledge" we are now held responsible for is not the whole of what is almost instantaneously *available* to almost everyone, but rather a small, shifting core of what might be called "temporarily famous" common knowledge. (Recall Andy Warhol's prediction of the future time when each person will be famous for ten minutes.) Getting items of information into the spotlight of temporary fame has become a major enterprise. Whether your problem is the eradication of Third World hunger, the deposition of an evil dictator, stopping the Star Wars lunacy, or selling cornflakes, your solution must begin with "advertising"—attracting the fleeting attention of the well-intentioned, and *imposing* that item of information on them.

So much information is available that mere accessibility is no better than invisibility. Most books that are published are not read, and even being read does not guarantee their influence. This depends on higher-order effects: a book must not only be reviewed, but (thanks

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to the reviews) be included on an influential list of books to be read, for example. If it achieves sufficient visibility in the higher-order structures, it need not even be read to have vast influence. This profusion of information filters, duplicators, and amplifiers is the product of helter-skelter competition, and there is little reason to suppose such a process is even approximately optimizing. On the contrary, there is probably scant direct relationship between the value of items of information and their capacity to exploit the publicity environment and reproduce themselves across the society.

Richard Dawkins' excellent book, *The Selfish Gene*, introduces the idea of what he calls *memes*—a "new kind of replicator" living in "the soup of human culture." Memes are, to a first approximation, ideas in particular forms—the sort of thing one might be able to patent or copyright:

> Examples of memes are tunes, ideas, catch-phrases, clothes fashions, ways of making pots or of building arches. Just as genes propagate themselves in the gene pool by leaping from body to body via sperm or eggs, so memes propagate themselves in the meme pool by leaping from brain to brain via a process which, in the broad sense, can be called imitation.[6]

The analogy between memes and genes runs deep, as Dawkins shows. Recasting my argument in his terms, my claim is that, thanks to *some* technological memes, we have entered a population explosion of memes—parasites that are overwhelming their hosts. Unless we can find some new ideas, some antibodies for these new antigens, hard times are in store for us. The new memes we need are *conceptual* innovations, not just new technology.

It is technology that has created this embarrassment of riches. Consider, in this respect, our obligations to those in misery on other planets. It is quite possible that there is life elsewhere in the universe, and if there is life there is almost certainly misery as well. Fortunately for us, however, the most shocking and gruesome calamities on other planets—plagues, dictatorships, nuclear holocausts—are nothing to us, because even if we knew about them (which, fortunately for our peace of mind, we do not) there would be absolutely nothing we could do about them. Perhaps we should be wary about proceeding with the project Carl Sagan champions of trying to communicate with the civilizations on other planets; after all, we might succeed and find that their first message to us was a heart-rending plea for help—

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together with detailed information on just how we could be of assistance![7]

Not long ago, measured by the astronomical or even the biological time scale, the Western Hemisphere was as remote from the Eastern as any planet is from us now. Even well into the nineteenth century, few people had the knowledge and power to have any clear obligations to anyone or anything beyond their local communities. The average person could not reasonably expect to have much effect on the lives of those in distant lands, and hence was absolved from worrying about them. Such questions just did not arise—any more than the question of what to do about starvation in other solar systems arises for us.

A few people of enhanced power and knowledge found, however, that they could not hide behind their powerlessness. Their attitude was captured in the slogan *noblesse oblige*—those of noble birth had special obligations.[8] While the slogan applied originally only to the titled few, the idea was subsequently extended to all those who had power, inherited or otherwise acquired. The price they paid for their "*noblesse*," in the extended sense of not having to devote their waking hours to providing daily bread and shelter, was an enlarged social purpose. In the nineteenth century, every well-read person could ask whether he or she should become fully committed to ending slavery, for instance, and many decided they should. Their efforts succeeded in practically eradicating slavery.

Others took on different causes, with varying degrees of success. It is often noted how curious and sometimes eccentric the focus of such people's moral sensitivities can be, both then and now. Some anti-slavery crusaders were strikingly oblivious of the suffering of their own poor, the degradation of their own servants, the exploitation of the workers in their factories. Today single-minded zealots may uphold the cause of environmentalism or animal rights, apparently unmoved by the outrages committed against their own species by various dictators—at least they devote none of their energies to action on these fronts. Similarly, there are ardent nuclear disarmers who do not care to reform the sexism out of their own language and practices, or who routinely discard unopened all mail beseeching them to enlist in the cause of Amnesty International or Oxfam.

There can be little doubt how these exotic specimens of do-gooder come into existence. We are *all* of the *noblesse* these days. We all have

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the daunting luxury of the time, energy, knowledge, and power to undertake a broader purpose than merely staying alive and keeping our immediate kin in the same condition. Technology has created innumerable opportunities for us to know, and to act. We want to deal responsibly with this bounty, but *we do not know how.* When we turn to the question of which priority should engage our best efforts, we drown in the available information, unable to make truly principled decisions. Our responses exhibit a sort of Rorschach magnification of whatever minor personal proclivities emerge from the noise of competing and imponderable alternatives. The results, as we have seen, may often be eccentric, but they are arguably better than the course chosen by those who sit on their hands and ignore all appeals, on the grounds that they cannot calculate—have no time to calculate—which appeal is the worthiest.

One would think that any solution there might be to this practical dilemma would stem from philosophy, and more narrowly from ethics, but much as I would like to relate that the humanists either have the answer or at least have undertaken the research program that ought to yield the answer, I must report that almost no direct attention has yet been paid to this troubling moral problem by professional philosophers.

The reason for this is not hard to find. Ethics, like any theoretical enterprise in science, has always been conducted with the aid of idealizations. Reality, in all its messy particularity, is simply too complicated to theorize about taken straight. A favorite idealization in ethics has been the useful myth of the moral agent with unlimited knowledge and time for ethical decision-making. For instance, consequentialist theories, such as the various brands of utilitarianism, declare that what ought to be done is always whatever course of action will have the best expected consequences *all things considered.* Although consequentialists know perfectly well that no one can ever truly consider all things—even all relevant things—they still choose to couch their theories in terms of what the ideally reflective and conscientious decision-maker would have made of all the available facts. This presumably gives one a standard of conduct at which to aim, if never in fact to reach. *In practice,* we tend to overlook important considerations and bias our thinking in numerous idiosyncratic ways, but *in principle* what we should do is what this ideal

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calculator of consequences decides will most probably maximize utility (or whatever we call the good consequences).

The plain fact that we are all finite, forgetful, and have to rush to judgment is standardly recognized, not implausibly, as a real but irrelevant element of friction in the machinery whose blueprint we are describing. It is as if there might be two disciplines—ethics proper, which undertakes the task of calculating the principles of what one ought to do under all circumstances—and then the less interesting, "merely practical" discipline of *Moral First Aid,* or *What to Do Until the Doctor of Philosophy Arrives,* which tells, in rough and ready terms, how to make decisions under time pressure.

My suspicion is that traditional theories of ethics all either *depend on* or *founder on* the very elements of friction that are ignored by the standard idealization. Information technology, by removing the friction, helps expose the weakness of much that has passed for sound in ethics. For instance, a bench test that most ethical theories pass with ease is the problem: what should you do if you are walking along, minding your own business, and you hear a cry for help from a drowning man? But almost no one faces predicaments with that logical form anymore; instead we hear, every day, while desperately trying to mind our own business, a thousand cries for help, complete with volumes of information on how we might oblige.[9] On this ubiquitous problem, traditional ethical systems are essentially reduced to silence or transparent handwaving.

This is too large a claim to support here, but I can at least sketch the problem as I currently envision it. How could we write the *Moral First Aid Manual?* Or, might we replace the manual with something fancier—an Expert System for Moral Advice-Giving in Real Time?

The fantasy of just such an expert system often lurks in the shadows of ethical theory. "If what I ought to do is whatever has the highest expected utility, how on earth shall I calculate it in the time available?" This question has been familiar for over a hundred years, and the standard response from the moral philosophers is well expressed by John Stuart Mill, who borrowed a metaphor from the technology of his own day:

> Nobody argues that the art of navigation is not founded on astronomy because sailors cannot wait to calculate the Nautical Almanac. Being rational creatures, they go to sea with it ready calculated; and all rational

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creatures go out upon the sea of life with their minds made up on the common questions of right and wrong . . . .[10]

This is as fine an idea today as it was in Mill's time, but the metaphor misleadingly invites us to ignore the fact that the future position of the heavenly bodies could *actually* be calculated in advance, using the technology of the day. Where is the Moral Almanac that would guide the moral chooser through the stormy seas of life? We are still debugging it.[11] Jeremy Bentham, Mill's contemporary, set out to create a "hedonic calculus," and while no one takes it seriously today, the descendants of this quaint museum piece are still being produced, elaborated, and, above all, advertised, not just by philosophers, but by "cost-benefit analysts," computer modelers, and other futurologists.

What should be evident to computer scientists, if still easily overlooked by philosophers, is that the idea of actually producing a reliable or authoritative consequentialist almanac of any generality is sheer fantasy, now and at any future time. Compare the demanding specifications for such a system with the now well-known limitations on far simpler forecasting and problem-solving tools. *Short*-range real-time weather forecasting, for instance, has reached useful levels of reliability by restricting itself severely to a handful of measures, coarse-grained data-grids, and relatively simple equations, and then exhausting the powers of the world's fastest super-computers. Detailed forecasting of the weather months into the future is probably computationally intractable under any circumstances.[12] If it proves not to be intractable, it will be only because micro-climatic effects will be shown not to propagate chaotically after all. Yet, we already know, from countless everyday experiences, that "micro-social" effects—some unknown individual's dislike of Tylenol, for example—can create major perturbations in the best-laid human plans and social trends.

Even supposing the prediction problem could somehow be tamed, the evaluation problem would remain. In chess-playing programs, the problem of when to terminate look-ahead and evaluate the resulting position has led to the framing of the *principle of quiescence:* Always look several moves beyond any flurry of exchanges and postpone final evaluation until a relatively quiescent board position obtains. This satisfactory, though not foolproof, strategy of chess design, is

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systematically inapplicable to the design of our moral advice-giver, because of what we might call the Three Mile Island Effect. It has now been several relatively quiescent years since the melt-down at Three Mile Island, but can we yet say, with confidence better than a coin flip, whether that was one of the good things that have happened or one of the bad? If our imagined system were to generate a future path of probability *p* with Three Mile Island as its terminus, should it assign a high or low utility to the event? The trouble is, of course, that in life there is no checkmate, no fixed point finitely in the future at which we get one definitive result or another, from which we might calculate, by retrograde analysis, the actual values of the alternatives that lie along the paths followed and not followed. So there is no way, and *could be* no way, to tune the parameters of any prototype expert system we designed—except by the invocation, as usual, of ideology and handwaving.

The suspicion that consequentialist theories are systematically infeasible is nothing new. It has fueled support for the so-called Kantian or duty-based ethical alternative for over a century.[13] As the Pirate King says to Frederick, the self-styled "slave of duty" in *The Pirates of Penzance,* "Always follow the dictates of your conscience, me boy—and chance the consequences!" The trouble is that such duty-based theories, while not always leading to results as comical or pathetic as Frederick's myopic posings and blunderings in *The Pirates of Penzance,* have hardly coalesced into a stable and compelling system of recipes for action. Kant's own *categorical imperative,* which he quite consciously conceived as the one and only rule that needed to be printed in the *Moral First Aid Manual,* appears today about as naive and impractical a guide as Bentham's hedonic calculus.

It is a step in the right direction however, and what *is* new is the opportunity to reconceive of these alternatives to consequentialism through the lens of artificial intelligence as responses to the inescapable demands of real-time heuristic decision-making. When viewed from this perspective, for instance, what would count as a justification or defense of an ethical principle shifts significantly. This opens up a promising research program in philosophy, in my opinion, and I think it will gain more than just jargon from its engineering perspective.

The first, general result is appealing: we can already see that, since *any* "system" for ethical decision-making must be bounded arbi-

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trarily by limitations that are far from content-neutral, no technological black-box oracle can give you a principled, objective, reliable answer to your ethical problems, no matter what anyone advertises. When the choice is between "flying by the seat of your own pants" on the one hand and paying to fly by the seat of somebody else's pants on the other, you are entitled to keep both the responsibility and the excitement to yourself.

ENDNOTES

[1]These reflections have grown out of discussions in the Norbert Wiener Forum, a policy workshop at Tufts, funded by the CSK corporation of Japan, and under the co-directorship, currently, of Professors Tadatoshi Akiba and David Isles. Earlier versions of parts of this paper were presented at the joint meeting of the Norbert Wiener Forum with its counterpart forum at Tokai University in Japan, July, 1985, and in lectures at the MIT Laboratory for Computer Science, and the Yale Humanities Center this Spring.

[2]Most recently and convincingly by John McPhee, in "Heirs of General Practice," which first appeared in *The New Yorker*, and has since been reprinted in McPhee's collection, *Table of Contents* (New York: Farrar, Straus, Giroux, 1985).

[3]"Even physicians, formerly a culture's very symbol of power, are powerless as they increasingly become mere conduits between their patients and the major drug manufacturers." Joseph Weizenbaum, *Computer Power and Human Reason* (San Francisco: Freeman, 1976), p. 259.

[4]Daniel C. Dennett, "Notes on Prosthetic Imagination," *Boston Review* 7 (3) (June, 1982), pp. 3–7; George E. Smith, "The Dangers of CAD," *Mechanical Engineering* 108 (2) (Feb. 1986), pp. 58–64.

[5]"Now I used to think that I was cool
Runnin' around on fossil fuel
Until I saw what I was doin'
Was drivin' down the road to ruin"
—James Taylor, "Damn This Traffic Jam"

[6]Richard Dawkins, *The Selfish Gene* (Oxford: Oxford University Press, 1976), p. 206.

[7]There are suggestive observations on the role of technology in expanding our moral universe in Peter Singer, *The Expanding Circle* (Oxford: Oxford University Press, 1981), and in Derek Parfit, *Reasons and Persons* (Oxford: Oxford University Press, 1984), part I.

[8]Duc de Lévis, (1764–1830) *Maxims, Préceptes et Reflexions,* is the first use I have uncovered so far in my casual inquiries.

[9]John Stuart Mill, in *Utilitarianism,* 1863, thought he could defend his utilitarianism thus: ". . . the occasions on which any person (except one in a thousand) has it in his power to . . . be a public benefactor . . . are but exceptional; and on these occasions alone is he called on to consider public utility; in every other case, private utility, the interest or happiness of some few persons, is all he has to attend

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to." I doubt that this was an entirely convincing claim in 1863; it is transparently unrealistic today.

[10]Ibid., p. 31.

[11]Mill's idea was that the everyday maxims of morality that people had "made up their minds" about could be shown to be reliable rules of thumb that followed, somehow, from the more laborious and authoritative calculations of utilitarianism.

[12]Very short-range forecasting of local disturbances such as thunderstorms and tornados is proving extremely difficult, but is currently receiving considerable attention from NASA and the expert systems community, among others.

[13]The Kantian philosopher, Onora O'Neill, in "The Perplexities of Famine Relief," in *Matters of Life and Death, ed. Tom Regan* (New York: Random House, 1980) offers a convincing analysis of the fundamental embarrassment of utilitarianism: two competent and well-informed utilitarians, Garrett Hardin and Peter Singer, addressing the same issue (what if anything to do about famine relief), holding the same ethical theory, and having access to the same empirical information, arrive at opposing counsels: one thinks the case is compelling for dramatic forms of aid; to the other it is equally "obvious" that all such aid should be withheld. See also O'Neill's *Faces of Hunger* (Boston, MA: Allen and Unwin, 1986).

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Anthony Smith

Technology, Identity, and the Information Machine

THERE MUST HAVE BEEN MANY TIMES AND PLACES when people experienced the sensation of living at a hinge in history, a point after which all thought and feeling would be different from all that had gone before. We of the 1980s are observing, or have talked ourselves into thinking we are observing, a multidimensional shift in technology, in scientific theory, in the prevailing models of the world that we use in daily life. We label this change the information revolution, or use some variant of this rubric to suggest that the *world*—not just the "Western" part of it—is passing out of the industrial and agricultural phases through some new formulation of science into an era in which, in ways too numerous, too ineffable, and simply too mutually connective to be described, much of the world we know is somehow being transmuted into a different state, one in which convictions and priorities of all kinds are to be subverted.

Moreover, the prevailing view of this alteration is that it is based upon a universalizing principle embodied in the computer and evangelized in information theory. It is as if humankind is being forcibly inscribed into one history, a history that is being rewritten both forwards and backwards, mediated, symbolized, memorized by the computer, the information machine *par excellence,* which will

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provide us with a psychic and cultural tool never previously accessible—a perfect and recallable memory of everything. It is thus a machine that can in a sense construct future circumstances.

"There is no doubt that all our knowledge begins with experience"—the opening words of the *Critique of Pure Reason* meet their first challenge in a technology that suggests a coming autonomy of knowledge within a civilization that has already handed over to scientific technique the validating power of all experience as knowledge. In other words, where science since Egyptian geometry and Babylonian astronomy has consisted of slowly accumulating knowledge derived from human observation, from practice, and while Greek theory added an extrapolatory technique by which that knowledge could be extended and tested, now the very processes of language and information are becoming the raw material rather than the masters of a newer generation of machines. Machines that separate knowledge from knower remove one dimension from humankind as subject and refashion knowledge as an element within our environment. That is the scope of the transformation and we, at any rate, are being encouraged to feel that we are living at the point of such a change. What are the implications for us as living selves?

All technics operate as extensions of modes of perception. The chipped flint altered primitive man's relationship with the other creatures of nature and shifted the social relationship between man and animal within their common environment. Every tool extends the senses and relocates the individual and the collective aspects of self. Even the technique of speech extends or initiates the operations of the self within its world, and thus the uses of parts of the body are the first applications of the principle. But of all the tools developed by mankind, those that mediate and extend communication exercise the greatest impact upon the human being's perceptual apparatus and thus upon the evolving understanding of self. For that process of understanding is conceptually tied to an understanding of the world or of a world: it is through the world that one derives the techniques and observations for the understanding of oneself. Even the Cartesian "ego" has to accept the existence of a prior world within which the processes of thought are initiated. We project something upon that world that in turn reflects back upon us, even prior to any intervention, any application of intention of us upon it. The cybernetic models that prevail in today's culture provide us with a self that is

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inextricably conceptually dependent upon environment, the rational processes of the ego and the forces of the superego emerging in mutual tension from what Christopher Lasch describes as "the unrelenting struggle between instinct and culture."[1] We live amid a flow of constant reinterpretations of the self, as the environment of nature, volatile in itself, is coated with technics that have come to constitute an inner chamber within which self and world mutually extend, constrain, modify, and consolidate their respective attributes.

The role of systems and media of communication in constructing selfhood is among the most pronounced and dynamic of the technological processes. The transforming power of information technology is the culmination of several centuries of development in communication. It entails, like other technical tools, an extension of perception but in doing that work it does more than technologies of transport, production, or extraction to alter the sense of the world and the position of the species itself within the dimensions of time and space.

Every society divides its past into eras that help the coming to terms with the present. We associate each era with a set of tools or techniques; in the past the eras have been divided according to the rise of cults and beliefs, or the symbolic interventions of great natural catastrophes. We tend today to look back at a long era of hunter-gatherers whose view of the world, expressed in cult and myth, reflects a distinct view of time and space, of migratory tracks, of loose forms of ownership of terrain, hard for us to describe or comprehend because our language has grown in ways that express our relationships with the world in quite different ways. Agricultural society occupies a different section of time in our historical imagination and revolves around the patterns of seasons and cycles of work and the domestication of animals—a world in which feelings and beliefs about the identity of human beings within the environment differ greatly from those of the world of hunters, though much of the cultic and metaphorical content of that previous era is subsumed within the language and culture.

Industrial society looks back on both of those epochs as "lost worlds," eras of feeling and being that are closed off within our imaginations and aspirations, only occasionally capable of transmitting a sudden shaft or vision. They can be summoned up in the emotions but are only sedimentary within a consciousness dominated by mechanized metaphor in a world transformed by a completely

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different natural politics. In this era the animal, the season, the terrain compel quite separate attitudes and foster utterly different sets of beliefs, including the very divisions into eras of past times. Those worlds are constructed in our consciousness through our own needs and our own sense of physical dependency upon the environment. The animal passes into a completely different relationship with us, as it now depends upon us for its survival since—in our belief about the world—its environment becomes totally subject to human will.

Classification of the past, however, is an attempt on the part of the imagination to provide an account of the present. Each new phenomenon with which a society has to cope—whether in production, transportation, or weaponry—tends to dominate the perennial task of reorganizing the past. The techniques of historiography, though these too adapt to the prevailing technologies and typologies of the historian's present, help to illustrate and explain each layer of contemporary reclassification.

In the 1970s, past eras of communication techniques began to be redrawn in the light of the establishment of "information" as a key to contemporary economic change. The search for the origins of the new emphasis on information as central to the mechanics of a modern industrial economy led gradually to a thorough repatterning of history, with predictive overtones. Post-industrial society has become a convenient label for a contemporary phase that in itself suggests a whole series of phases—or relabellings of the past.

Some began to believe that in the area of the new computerized communications one could discern the central mechanism of a general transformation of the economy. From such discussions in the middle of the 1970s we have developed the idea that we are passing into an Information Society—an idea that has now become more than a theory, perhaps even a nervous obsession. The "post-industrial" explanation of the way in which the computer was transforming work was enveloped in a broader remaking of all the phases of human history around eras of communication or information.

It is important to look at the changes that do take place in society and in human consciousness when the dominant means of technology changes. This certainly explains the enormous growth in interest in the changes that took place between the fifteenth and sixteenth centuries, when the Gutenbergian revolution took place. In the center

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of the information society idea is the sensation that we are, as it were, rerunning the Gutenbergian revolution in the 1980s, but with a different technology.

What print succeeded in doing in the fifteenth century was unifying the consciousness of text as such, while bringing together text generated in different times and places. In that sense print created a revolution in the consciousness of space and time. It intensified the intellectual awareness of textual differences; it made the technique of comparison a basic instrument of understanding. It introduced at the same time a notion of standardization; printing was one of the first of the technologies that helped to standardize elements in our environment. It standardized calendars, dictionaries, maps, and diagrams, and in doing so it created in our minds the notion of the fixity of knowledge in certain areas of life. Of course print did not help to transport fixities only of textual information across time and space; it also made possible repeatable pictorial representations. In this way it left in our minds a visual as well as textual dimension to this new fixity of knowledge.

Moreover, printing industrialized time, space, and quantity as tools in the enhancement and reproduction of knowledge. Shifts in intellectual attitudes in the post-Renaissance period are clearly related to the arrival of printed text. The work of Elisabeth Eisenstein in documenting the social changes that took place in the first Gutenbergian era has, together with the work of Walter Ong, opened up these topics; their writings are two great fascinating stores of ideas from which one has to draw almost unconsciously today.[2] Systematization of thinking is perhaps the common factor of change in human culture to which they both draw our attention. The notion of alphabetical order, the introduction of fixed forms of punctuation in the representation of language as text, the growth of indexes and catalogues, and all the other elements of typographic fixity that came with printing, evolved in status into being crucial elements within our intellectual life. They altered notions of what constitutes civilization itself.

Before the Gutenbergian revolution (in a newly constructed era of "chirographic culture") intellectual skills revolved around the manipulation of abstract logic, which indeed depends upon writing, but not upon printing, nor upon simultaneous access on the part of many readers to the same text. So the characteristic genres of the chiro-

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graphic era—such things as rhetoric, polemic, and disputation—implied the use of the mind to argue abstractly, employing techniques of logic, which is a kind of mental technology. In typographic culture, however, intellectual ideal form begins to shift from polemic to the search for objective knowledge. The speaker becomes more and more separate from the knowledge that he is providing. And the knowable also shifts: knowledge inhabits a text that has escaped the constraints of time and space and to some extent of persons.

Consider the very earliest discussions of the intellectual implications of the coming of writing. I am thinking of one of Plato's texts where he inveighs (through the voice of Socrates) against the explosion of writing into a society in which previously the knower was not separated from the known. When in Socrates' story the god Thoth brings writing to the king of Thebes and says: "This will help the people of Egypt to remember," the king responds: "No, you have imported forgetfulness into my kingdom!" Writing enables the first separation to occur between the knower and the known. Indeed, as Plato goes on to comment on this, he says that the problem with writing is that it travels from place to place and gets "into the hands of people who have no business with it." In other words: the audiences become irrelevant to the speaker, to the holder of knowledge. That knowledge becomes subject to a set of complicated and mediated relationships, mediated by the text and those who hold and organize the text. It is one stage in the long process of industrialization, now believed to be reaching some kind of climax in the information-based society and economy of the late twentieth century.

Print was a necessary condition for the establishment of the possibility of objective knowledge and the possibility of seeing the possibility of knowledge as objective. This has been a structural factor within the new Western culture that we have inhabited for half a millenium. Electronic culture represents not a displacement of either the chirographic nor the typographic; indeed, the typographic was not a displacement of the chirographic, it was a superimposition upon it. We are living through an era in which the electronic mode is being superimposed upon this typographic mode. It is very difficult, since we are living in the middle of that transition, to sort out the implications of this particular form of new information order. But what it basically does is abolish the unit of print, the type, as the

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primary unit of knowledge, and substitute for it the bit, the statistical entity, the elemental logic of binary opposition.

We can now begin to tease out many implications of this great series of changes that we face. The binary digital logic of the computer replaces the serial logic of the objective culture of typography. The notion of binary opposition cuts across all levels of any structure of information. New knowledge moves away from the possibility of objectivity into an area dominated by statistics and probabilistics. We are leaving the era of Gutenberg and entering the era of Shannon, in which information is dependent on a basic unit that offers the illusion of certainty through the probabilistic reading that is taken from the digital bit stream—the totality of digital knowledge, reduced to the dots and dashes of the computer.

Perhaps one can illustrate this crossover by using a parallel from music. In the system of recorded music, established early in the century on the basis of analog waves, one could say that the analog signal was derived directly from a performance of the music and that what was implanted in the recording was an actual, objective representation of the original performance of the music. When you listen to a digital recording, however, you are hearing something that is far more convincing to the ear, because of the ear's impreciseness. In fact, the reception in digital recording is of a representation that results from the *sampling* of a signal. The auditor is receiving an artificial construct between the orchestral representation of the music and the ear. There are purists, who have argued that we should hold on to the analog signal and reject the notion of digitization, because it is so removed from the original performance of orchestra or voice. The digital recording is detached more fully from its originating time and space. But in the era of the computer all information passes through this stage of sampling. At the heart of computerization of information we are abandoning a technology that attempts to give the symbolic representation of an actual speaking event, an informational event; and we are moving into a phase where there are more processes of industrialization between ourselves and the original utterer of the information concerned. This may seem a remote, even abstract way of putting it, but computerization entails a usurpation of the relationships between knower, known, and recipient of information.

There exists no longer a line of validation back to a pure text. The first Gutenbergians faced a world in which knowledge was something

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lost but to be recovered. Knowledge had occurred in the past, and it was considered the task of the intellectual, as it were, to restore it. The whole notion of pre-Gutenbergian knowledge was that of a nostalgia, an intellectual nostalgia, yearning for that which had been known but lost.

Since printing knowledge has become subject to a process of progressive augmentation—through the comparison of texts, through the elimination of time and space as a constraint upon information—knowledge becomes the quest for something in the future. Research, in the modern sense, replaced the tasks of medieval scholasticism, and its techniques. In the electronic era, however, knowledge becomes again subject to a process of interpretation. There is no longer any certainty in knowledge. In the new global Alexandria of computerized information there is no ultimate perceptual security, no ultimate validation of a text back to an original writer or to an original authority. It is a culture based upon a ceaselessly interpretative notion of knowledge.

The implications of this development may emerge a little more clearly if something is said about the state that has now been attained in this process of changeover from the Gutenbergian to the Shannonesque modes of knowledge. We are at the stage of an evolution in which we are still highly conscious of the technology itself. The computer is not yet transparent to us. We pick up a printed book but we do not think of the printing in the text; our culture has simply trained us to fuse the notion of text with the notion of information. Our senses take us directly to the sense, to the information, once we have learned to read a language fluently. Technologies constantly strive towards the condition of transparency. When you are hammering a nail—to use Heidegger's example—if you are too conscious of the hammer, you cannot do the work. The carpenter is not obsessed with the notion of the hammer, because—if he is a real carpenter—the hammer is an extension of his hand. We only become conscious of the tools when they function badly. When listening to recorded music, we allow our consciousness to pass through the technology. In the case of computerized information, the system is not yet transparent. Even in the case of the telephone, which is one small and primitive device of the electronic era, we are still fairly conscious of the equipment. We feel ourselves to be speaking to a person at the other end but there is still considerable consciousness of the telephone as an instrument. Technologies always develop to the

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point at which they function in a way that seems to be non-technologically mediated. Technology eventually withdraws, and ceases to draw attention to itself as a novelty.

In the case of the computer, we have clearly not yet reached that point, except perhaps in respect of the pocket calculator. We are probably a decade or more from the period at which we shall be sufficiently familiar with the new tools of information—and those tools sufficiently familiar with our languages and our need—to transmute our perceptions from culture to culture. We are still a good generation away from a state of transparency in the new information technologies, but when those new information techniques are perfected, the result will be a still further reduction in the constraints of time and space upon the communication of knowledge. It is as if the whole world of information and interpersonal contact were to be placed in a single plane of space/time, detached from physicality, as computerized information to a great extent already is. Knowledge must move one stage further from that typographic fixity into a relativistic, interpretative phase. There occurs a kind of paradigm shift when we move from the analog to the digital. It is a shift from the objective to the relative, from certainty through the representation of knowledge as objective to a different kind of certainty derived through a satisfying interpretation of varying versions of information. It is a shift from precision to probabilism, and it echoes many other recent shifts in the sphere of science and culture.

One can discern the changing paradigm throughout our culture as functions become computerized. Take the example of the pricing system: a good establishes its price through transactions between individuals interacting physically, but if you look at the modern computerized markets, used today for determining the price of currencies and commodities, you are witnessing the instantaneous interpretation of a myriad of transactions between actual individuals abstracted into something called a "price." That price exists only electronically; it is derived from a series of electronic representations. It is relativistic and in constant flux, merely an interpretation of a large number of transactions into computerized information. Every transaction is an event based upon the interpretation of other such events and gives rise to an objective statement of a "price," but the "market" is an abstraction consisting entirely of data.

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It will take decades to work the dimension of relativism into our culture. The process hitherto has been attended by a rather abstract optimism, indeed it has enveloped it in these recent years; it strays into almost any attempt to describe the process. We need to gain, however, some kind of evaluative purchase on it, for it entails the progressive strengthening of economic activity over the social and political dimensions of life. That cannot simply be lived through, despite its overwhelming inevitability, without some attempt at moral assessment.

Imagine three villages that have a common problem. They are plagued by burglaries and all the villagers have become tremendously nervous; whenever they leave their houses, they are broken into and robbed. All of the villages contain a large number of people who are without work. The three villages adopt different means of dealing with the burglary problem. In the first village, the people make a decision that everyone with time to spare should stay at home and look out of the window. Very soon this informal social process seems to cure the problem of burglary. In the second village, they decide to recruit and train their own police force since they also have much unused labor available. This also seems to cure the problem. In the third village, they decide to use the most modern techniques and acquire a large number of electronic devices to monitor the activities of every home, the movements of everyone in the village. The method is highly labor-saving and effective. The burglaries cease.

All three villages solve the problem. The first village, one might argue, is a subsistence economy that contains an enormous redundancy of information, but has preserved the autonomy of the individual by keeping the information uncommoditized. The second village is clearly an industrial society, in which certain interpersonal relationships have been specialized. The same village probably has many doctors, psychologists, and lawyers and others whose specialist skills have gradually sequestrated the autonomy of individuals, replacing it with professionalism and bureaucracy. The third village is an "information society," in which the individuals are in a sense served by their sophisticated equipment, and in which a whole range of interpersonal relationships has been commoditized by turning them into information. The commonalities of the society have been absorbed into the information work of electronic equipment. The penalty paid for this solution to the problems of the society is that the

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internal relationships are digitized and therefore reified. When the domestic milk delivery service is paid by electronic transfer an enormous redundancy is "saved" by the society, but the relationship between the "milkman" and his customers becomes itself a commodity, where previously only his labor—and the milk—had been commodities. That is what the information society is offering as a by-product of a new stage in the mechanization of the economy and the informatization of culture.

In one sense, the perfect information society should be totally self-transparent: in it everyone can find out and know everything; it is in this sense a perfect community. Yet, it is also the negation of community, where so many aspects of human relationships are technologized. It is, unlike industrial society, a society in which it is difficult to pin responsibility on anyone for any particular range of activity. Every problem is technicized and easily transmuted into the electronic mode in order for a solution to be found. People communicate, when they do something together, when they share a world of making and doing. The information society must tend to shatter what remains of that common world. When relationships, defined according to stance towards the central means of production, are transmuted into relationships defined according to links with flows of information, quite new class patterns must emerge; indeed patterns not of "class" in the traditional sense, but of constantly evolving links and loyalties.

Privatization and the market place are essential counterparts to the information economy, but this by-product represents the mystification of authority; a statistical and ineluctable force takes over the command tasks; responsibility dissolves; economics gradually absorbs anthropology.

There is a wider intellectual context to these changes. We are finally changing our image of the world from a Victorian mechanistic model to a novel cybernetic model based on a new biology and on ecology; we use the metaphors drawn from these areas of disquisition to look at our society and in a sense to justify the transformation to ourselves. With the use of the new post-Victorian metaphors has come also a kind of false consciousness, reconciling us to a stage in our society that might otherwise be morally unacceptable. There are highly tempting aspects of the new social environment. On the one hand, the doctor does not make home visits any longer; he or she

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talks to you by telephone. On the other hand, the doctor has access to a much larger body of expertise which cannot be carried around in a leather bag. Whole societies can have access to ranges of information that were previously the monopolies of other societies, but in accepting them the former accept also the process by which the alien expertise encodes the social relationships of the latter.

In a technological society, the whole environment shifts; technology imposes a second layer on the processes of perception. But in an information society it is as if perception occurs within a dual environment; one is not just driving around in a car, but seeing the entire world through the window of a car. Not just use but perception of the world is mediated and limited by the capabilities and constraints of the technology employed.

We become in another sense spectators of reality, and the notion of the autonomy of the individual within the technological reality becomes harder to sustain. The individual has the sensation of being dependent upon inexorable forces, forces of markets as well as of technological possibility. At the same time we live within a growing myth, which was initiated in the phrase of McLuhan, "global village"—the myth that through technology the human world will somehow grow into a single community or a substitute for a community. It is as if technology cancels the inconveniences of time and space. This is a myth, an optical illusion. It is fundamentally totalitarian—perhaps a different and palatable version of totalitarian culture.

Like all totalitarianisms, it begins with a falsification of history, or the reification of history. The cybernetic model, the Shannon view of the world, turns the universe into a kind of artifact; it suggests that human behavior is entirely representable in the electronic mode. It is no accident that the phrase "artificial intelligence" has become such an important term within the culture of those responsible for the informatization of society, because, if intelligence can be artificial, then the randomness of history will disappear. There is no room for vast human redundancies of information in a society where it is possible to conceptualize the function of intelligence as "artificial." Clearly, what in the past we have thought as constituting intelligence is not artificial. It is more than a matter of words. If it is artificial, then it cannot constitute the function of intelligence. If AI is believed to be intelligence then it is the nature of our self-belief as humans that has

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changed, not the actual functions of what we believed previously to constitute intelligence.

If we come to believe that it is possible to capture intelligence within artificial devices, then we shall come to believe that human beings can make their own history, a profoundly totalitarian idea—indeed, perhaps the essence of the totalitarian. If we are capable of making history then we have nothing to learn from it. There is no randomness, there is no community; we are already several generations remote from the first village, where people stare out of windows and collect through autonomous observation the living and unconscious data about the society in which they live. Information society is, as it is currently conceived, a society incapable of being surprised, except by its own miscalculations.

In such a world the result cannot in practice turn out to be what is being offered—the infinity of choice within a plenitude of information. This is what the proponents of information society offer us—a world of infinite possibility. Actually it seems to offer the opposite of that—an extremely brittle world, in which the doubts and ambiguities that occupy the spaces between people, institutions, and nations have been evacuated.

I once found a nineteenth-century newspaper that began a long report something like this:

> A despatch reached Lord Palmerston three days ago via the Paris telegraph which had collected it from a messenger who had brought it by stagecoach from Marseille who had collected a package from a cargo master sailing from Alexandria who had received it from a desert trader from the Red Sea, where a south-eastern tea shipper had presented a message passed on urgently by a Chinese trader, which informed the Foreign Office that Her Majesty's troops had exchanged fire with the troops of the Emperor of China; it would seem therefore that this country is now at war with China.

There is now no space in our world, in which the materials of international relations are instantaneous and complete, for there to be doubt about whether one is at peace or at war. The penalties of error are global destruction. The market of diplomacy is an almost exact market, without space for rumination. We live in a space in which the chief advantage of distance (the passage of time necessary for communication) has been lost. The great protection provided by doubt has been undermined.

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Similarly, in a society in which all information about all commodities is perfect, even before they are harvested or mined, even before the weather has even occurred that will determine the crops, when all readings of nature are possible prior to the event, very little space is left for doubt, and therefore weaker countries that produce basic commodities depend for their stability all the more on their powerful neighbors. As that dependency tends toward the total, the need and desire of the more powerful to control becomes all the greater. In the society we are evolving, the implications of which we are still seeking to acquire, there is less and less space for autonomous action; areas once governed by guess and judgement, leaving space for error, have disappeared. We are living in an era of more perfect markets leading to more perfect knowledge but in an extremely brittle and dangerous world, both economically and militarily.

There is a sense of excessive coincidence, even of absurdity, inherent in an intellectual operation that insists on dividing history into parts, turning points situated overneatly in the present or in the recent past. Nonetheless, I shall indulge, for a moment, to help my argument along, in such a schematization. The construction of a fully technicized environment corresponds—in those societies that have perfected it—with a fully secularized culture and a perceptual system that attempts to shut out from the self a vast realm within which individual and social identity were very largely fashioned—the realm of the spiritual, the non-material aspects of the universe, which, of course, did not seem particularly non-material to those who believed in them. In a medieval painting the observer can see the material depiction of that realm; in modern psycho-analysis the conception of an unconscious is an attempt to materialize a domain of individual and collective social experience within which the conscious self can try to find its bearings. The two are not the same. For the medieval painter the modern self would appear merely to be totally underdeveloped rather than to be operating at a higher level of certainty.

The late twentieth century examines that lost realm, half of the terrain over which the pre-technicized self was free to roam, in puzzlement, not because it has become invisible, but because there are no longer the perceptual and intellectual vehicles in which to navigate. We are chess players who have not been taught how the pieces move. We have lost the convictions and beliefs that made possible the outlook within which a whole armory of techniques of self-analysis

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were available. There hangs over our culture a faint memory of how the self once was, of how an individual participated in a unified cosmos, like the nostalgic smell of a long forgotten dish floating across a kitchen that contains neither the recipe nor the ingredients. But we know there was such a dish, and its cooking was dependent not upon access to a lost recipe but to a whole cuisine, a complete discipline which has been, by stages, displaced as the universalizing propositions of scientific practice have divided experience into the validated and the irrational, employing a unitary criterion of verifiability. This great divide in the evolution of human experience has not, of course, descended upon us suddenly but has in the recent past become total and universal, corresponding to the full technicization of our approach to the world as environment; we have acquired what Gadamer calls "an artificial counter-reality,"[3] as a shaping dimension of that environment from the mutual reflections with which we take our own identity.

ENDNOTES

[1]Christopher Lasch, *The Minimal Self: Psychic Survival in Troubled Times* (New York: W.W. Norton and Company, Inc., 1984), pp. 23–59.

[2]Elizabeth Eisenstein, *The Printing Press as the Agent of Change*, vols. I and II (Cambridge, England: Cambridge University Press, 1979); see also Walter J. Ong, *Interfaces of the Word: Studies in the Evolution of the Consciousness and Culture* (Ithaca, NY: Cornell University Press, 1977), and *Orality and Literacy* (London: Methuen, 1982).

[3]Hans-Georg Gadamer, *Truth and Method* (Crossroads, NY: Crossroads Paperback Company, 1982).

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Observations on Art and Science

Stanley Cavell

I side with those who find an asymmetry in the relationship between the arts and the sciences, but perhaps I picture it differently. An asymmetry may exist between the roles these institutions play in a given culture: everyone knows some popular view of what goes on in science, or in some particular scientific theory, but there is nothing comparable to be called a popular view of the current state of the arts, or of the work of a particular artist. Not only artists but politicians, humanists, journalists, are prepared to use some sort of scientific phrase to describe current developments of apparent or real interest to themselves: they are willing to rely on the hearsay of science. But what is hearsay about the arts? Here, the issue is less that of rumor or reputation than of fashion and pretense. It might be interesting to consider the ways in which hearsay science, or perhaps the effort to ape science, enters various kinds of writing, such as literary criticism. There are critics who seem unable to finish an article without alluding to "interdeterminacy," sometimes even mentioning physics, though the tendency is perhaps fading. By now the phrase "frames of reference" is so common that I suppose it is not necessary to recognize that the concept might have an origin in the exact sciences. Sometimes one's flesh creeps when non-scientists use such terms; but perhaps that response is itself suspicious. As in the case of every borrowing (if that is what this is) its value is determined only by the results. A recent concept in literary circles is that of "undecidability." How much of its prestige comes from an idea, or the aura of an idea, that Gödel (or somebody) underwrites the transfer of logic to literature?

I agree with Howard Gardner that on the whole scientists do not make comparable use of the arts. An artist at work may want for his or her own purposes an image from science, or its sound; a scientist on holiday may be pleased to think of himself or herself as having an aesthetic sensibility. But the places the sciences inhabit do not on the

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whole have or need the arts in them. Arts may be studied at universities, but those are perhaps not the most efficient and encouraging places for people creatively involved in one of the arts. It would be ludicrous to deny—hence perhaps it is a little ludicrous to insist—that both science and art require, and reward, creativity. To think usefully here is a function of being specific. For example, art and science each has its elegance, but artists sometimes may wish to avoid elegance, or finish, or beauty of a kind. What sense would this make in science? Both science and art function through precision, accuracy, authority, apprenticeship, argument, rhetoric, definition, community, example, experimentation, intuition, stubbornness. . . . But what is the point of saying so without specifying their differences?

Artists mentioned in our discussion, such as Van Gogh and da Vinci, were not painting only for their peers. They expected their works, created them, to survive beyond the people who could accept them when they were made. The works are available to people who might argue or fight about them, but who can neither reproduce nor continue them, who cannot to that extent understand them, and whose acceptance is the acceptance of a public, parts of which may be appreciative and parts of which may be unmoved. But a divided public is not a crisis for an art; it may, on the contrary, make a movement of art famous. (What does it mean to speak of a scientific "movement"?) Scientists, on the other hand, do not work for a public but exclusively for their peers. (I leave aside the question of their clientele or patronage.) Science can be said to have no public, only beneficiaries or victims. All and only those who are in principle capable of producing science can understand it, so the acceptance or rejection of peers cannot just be irrelevant. A division of acceptance may constitute a crisis within the scientific field. It is perhaps for such reasons that art is said to be both less exclusive and more exclusive than science. I do not find that a helpful summary, since the reverse can equally be said. What, to my mind, need to be specified are the internal and external institutional forces in play.

The question was raised as to whether Einstein and Picasso were more like one another than they were like ordinary workers in each of their fields. I suppose I can understand what workaday scientists are—very intelligent people who make contributions to the development of ordinary science. It seems to me that such workaday scientists and Einstein (if I understand what that name was used to

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figure) share strong bonds. On the other hand, Picasso and those he figures, say "advanced artists," may lack such bonds with those one might call workaday artists. But what makes these divisions between the advanced and the workaday? In other centuries, when art was primarily a function of craft, the heights and the depths might very well have been close together. And in the present century, certain artists may largely be neglected who will still one day largely be heard, perhaps after they are dead. You may say that the same could happen in science. *Is* such rediscovery the same in science? Suppose that a strong bond scientists share is of the romance of science itself, the adventure of knowledge. Scientists can say "we"; "We are on the frontiers of something big"; "We will understand how the brain works before the century is out." But major artists may as soon inspire disapproval as receive encouragement from "good" artists, and yet these latter may gain support from a public while major artists fail to. These differences can obtain, even though personal envy and public competitiveness are as intense in the purity of science as in the innocence of art. One may even wish to say of the respective traditions of science and of art that the relations between tradition and the individual talent obey different laws (in different periods?).

It is not surprising, then, that I am interested less in the sense, or illusion, of some general creativity shared in by scientists and artists than in the mutual hostility and mistrust at present (where it exists) between artists and scientists and in whether there is any symmetry in how each side perceives the other. More than one scientist here has spoken of the guilt of scientists, who are worried that they have become the menace rather than the salvation of the human race. This concern was more than once associated with the sense that scientists are instructing a new generation of practitioners who may never understand what the pursuit of science meant to their teachers. It is as if the teachers fear that they are providing training in techniques and politics, but not an access to a body of work that will eventually exert its own inspiration. While this concern was directed to "big-time" physics, I should like to add that a certain dimension of guilt is shared by the comparatively impoverished, comparatively local, field of philosophy. Few would suppose that unfaithfulness to the ideals of philosophy is causing the danger to the world that the dissociation of science causes. Yet from time to time I worry similarly for my students in philosophy, from time to time saying in effect to them:

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Remember it is philosophy you are studying, exactly the subject whose problems must not be treated as given, as if their importance is assured, the discipline whose very existence, and importance, are to be held at risk. Such outbursts would be a response to the danger of self-neglect, inner loss, which I claim presents the greatest threat to philosophy. It may take longer for the loss of genuine philosophy to become manifest, but then inner loss threatens every discipline. I mention the case of philosophy because I would like to see the element of guilt used practically, not dissipated in overly narcissistic sentiment; used to provide an opportunity for personal and perhaps for social change.

The idea that such issues may be resolved by exposing physics students to a little art seems to me to be hopeless..In order for such a proposition even to seem to work, the students would have to think about art when what you want them to be thinking about is physics. They would, in short, have to become artists—to care whether their art is going to survive. Survival seems to be the point about one version of modernism, art starting to be about art, painting about painting, music about music, writing about writing, and so on, in the most intense and relentless way, when it starts being felt in the most relentless way that "apart from me, this is going to vanish"; as if without what I do (whoever has this feeling) the human race may forget what it was to be curious, what it was to be compassionate, what it was to want to make beauty, to want to create.

The sense of the fragility, or contingency, of these monumental cultural achievements weighs on our discussions, the possibility that human creativity as such will vanish. I am reminded that disorder and destruction seem to be inherently human impulses, the shadow side of creativity. The wish to make something, to counter destructiveness, to leave the world marginally better than you found it, to mend it, is at the heart of both the arts and the sciences. I am reminded here of a recently published, fascinating book with which I have great problems—*The Body in Pain* by Elaine Scarry. I find this book (in the opening chapters that I have so far read) philosophically retrograde, but it takes up matters of immense importance. Scarry approaches the concept of creativity by investigating counter-creativity, of which she regards the two main forms as torture and war, which are as if produced by an aversion to the idea or fact of intactness, or in despair of it, as in the slides Dr. Eric Cassell showed our group, in which

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scenes of natural or aesthetic disorder are signs of disease. We find something of this idea of order and health as victors over social violence and darkness in the romance of medicine, as that occurs in the face of Dickensian nightmare. I have in mind the young doctor in *Bleak House* whose scientific reasonableness and faithfulness in caring for Esther has the power of deep wisdom. I call Scarry's book philosophically retrograde for perhaps too personal a cause. It seems to me that her refusal to see the pertinence of Wittgenstein's *Philosophical Investigations* to her concerns is destructive of efforts to bring philosophy back into the human conversation, and vice versa. She cites from the *Investigations* one obscure passage bearing on an edge, or fantasy, of the concept of pain, as if just to dismiss the pertinence of Wittgenstein's voice. But joining the idea of the human body, centrally as in pain, with the sense of the denial of the knowledge of others as the annihilating of others, of otherness, is precisely what skepticism is about, as this daily structure appears in Wittgenstein (on my reading of him). Torture is absolute denial; but polite denial is civilized torture, hence a reasonable place to cut it out.

The most urgently, often implicitly, recurring question, to my mind, posed by the anxieties revealed in our discussions concerns education. I am sure I am not alone in feeling that the issues we raised explicitly about teaching artists some science and scientists some art come very late in the day. Yet worried as we are about where we are leading or leaving ourselves, we do not plan to give in to despair. As Leon Cooper said, we would not be here if we just despaired. Here again we touch on the idea that science and art wish to better the world, not only to have good consequences—one interpretation of progress—but to demonstrate that the actual process of working in these fields reveals the world as a place that elicits creativity, and hence hope. It is an idea that inspires the vision of ourselves as in an unending struggle between the wish to create, and the desire to destroy, as if thwarting the impulse to accept the world and others in it produces the impulse to reject them, the desire for annihilation. In this sense, the common threat to mankind of annihilation is not merely our major public fear but our final private wish. This wish—for vengeance, call it—may pose our most intractable danger. It is a wish I have found (intellectualized) in what philosophy calls skepticism and in its efforts to overcome it; it is recorded in Nietzsche's diagnosis of nihilism; it recalls Freud's vision of a death instinct. The

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perception of a commonly shared vengefulness toward the world finds its most persuasive, if most neglected, study in Emerson's description of the mass of us as pursuing lives of "silent melancholy"; Thoreau says, "quiet desperation"; it is the despair that cannot see itself, that disclaims, or disheartens, expression. That figures who perceive our accelerating hopelessness (Emerson, Nietzsche, Freud) are exactly ones who are academically marginal (at best), is for me depressing. It is something I meant in speaking of the particular and general danger in the loss of genuine philosophy. (I add this gloss and these names now, reading over the transcript of my improvised intervention in order to edit and amplify it, out of the recognition that I had suppressed these figures of my concern in obedience to their marginality, in league with the academic wish to certify my own respectability.)

I have a practical suggestion. In 1750, Rousseau composed his remarkable *Discourse on the Arts and Sciences* in response to the Dijon Academy's announcement of a prize for a discourse on the question of whether the progress of the arts and sciences has contributed to the purification of morals. I suggest we announce a prize for an essay on the effects (moral among others) of the arts and sciences in our period (their costs, benefits; individual and social; local, national, international), proposing to publish the winning essay, and worthy competitors, in an issue of *Daedalus*. Suppose that a hundred people are moved to spend at least one night trying to write the opening lines of an essay on the subject. Perhaps ninety of them will give up, flooded with their own ignorance, or with too many things to say, and so on. That experience should itself be instructive, since each will find the issue more complex than he or she had anticipated. Among those who persevere will be some who are as likely to make a fresh, useful contribution to the subject as anyone present at our discussions. It is not clear what lines of expertise are best placed to yield results on this question. I have imagined that a creative scientist who feels painfully the scientist's loss of control over the goals and fruits of science may seek to reinstate a better relation to science by teaching its beauty. And I asked in effect whether you teach the beauty of science better by recommending the beauty of something else or by the beautiful teaching of science. Perhaps we could find it in ourselves to reopen the ancient philosophical question whether, or under what conditions, virtue can be taught.

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A scientist may imagine that art can help science by restoring the lost sense of scientific community and communication. But to look to art for reparation here sentimentalizes artists, who have their own problems of community and communication, and are meant to have them, to take them on. Artists are not essential to a university. In a university artists tend to mumble. Remember listening to their speeches on the floor of the faculty. They convince mostly nobody. Yet universities seem to want them present. We praise them in principle. But in fact, they do not function in our day-by-day way. Are we grateful for that, as if they are martyrs to a cause we all share? It was suggested that in the organization of "big" science there is a priesthood that manages it. Science, science at its best, lends itself to organization of a kind that universities can welcome and reward. There may be, within this priesthood, a cabal that keeps somebody out and brings somebody else in; a group that distributes power will split itself in alliances. Now the world of art *can* be organized in something like this way; but presumably no one here imagines that this (now) makes for art at its best. A reason science can be organized by a university is that science depends exactly on the exchanges of education provided by higher educational institutions. Whereas artists persist (and philosophers should persist, since philosophy should turn a face both to science and to art) in asking what their education should be. It is a valuable question; people who persistently ask it of their lives are valuable. But it is a frightening question for those who know in advance what the purposes are to which they are willing to put their education in service.

* * *

Leon Cooper

We might ask why this question of the difference between art and science is posed. Why are we not talking about the similarities or differences between a painter and a musician, or between a sculptor and a poet? Why is the distinction between the scientist and the artist of special concern? I would like to suggest that this is less an intellectual than a sociological question. It is perhaps because,

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unfortunately, more and more people who call themselves scientists live, think, and work in a different part of society, both intellectually and socially, from the part inhabited by those who call themselves artists.

There are indeed enormous differences of style in science. Yet, one characteristic of science is that the way things are said in science is almost always less important than what is said, whereas the way a concept is expressed in art is almost always more important than what is expressed.

There is a vast difference between science being created and science being presented (in textbooks, for example). For science being created, I see a closeness between art and science. Creating a painting or a sculpture, a piece of music or a piece of science, involves processes in which intuition is important. The process is not entirely logical—quite distinct from formal presentations in textbooks.

I would like to return to a point made earlier about Galileo, to which I took objection, because, in my opinion, it diminishes the importance of what Galileo did. The importance of his treatment of falling stones is not that he was right and that Aristotle was wrong, but that he chose to ignore what experience tells us, that a heavy stone falls faster than a light one. Galileo held the view that this small difference is not important. He chose to regard as relevant what would occur if air resistance was removed. Now the decision that the air is extraneous represents a point of view, a new way of looking at the phenomenon. It is a tremendously fruitful approach, for the inclusion of the resistance of the medium as part of the fundamental phenomenon was one of the reasons the Aristotelian approach had come to a dead end. In this respect, the scientist and the artist are in very deep accord because there is a sense in which the artist selects; he decides what to look at, what to emphasize; in a certain sense, he presents a world view.

Consider the two different ways of looking at the world represented, for example, by the Impressionists, and the Cubists. Presumably, both live in the same world, but a decision is made to select particular aspects of it, to organize it in a certain way. A painting of Monet could be regarded as Monet's point of view of what to look

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for, or how to regard experience. I think there is clear evidence for this. If we had *Time* magazine in the early nineteenth century, it would have been somewhat unlikely to find a picture that looked like a Monet. On the other hand, today every magazine, popular or otherwise, contains sketches that may or may not have the same skill or originality, but clearly display a way of representing the world that was created by the Impressionists.

I would like to give what I regard as a magnificent example of creativity in science, to present some of the process, and some of the ambiguities and problems. Consider Einstein's Theory of Gravitation. Einstein was fascinated by what fascinated Galileo: that (neglecting air resistance) all bodies fall to earth at the same rate. Now, in Newton's theory, this is explained as a consequence of accidental coincidence of two very different constants. Einstein wanted to produce a theory in which this phenomenon was really the heart of the matter. He worked on the problem for ten years, and produced the famous Theory of Gravitation in which the gravitational phenomena were explained essentially in a geometrical manner. It is intriguing that for a vast range of phenomena (essentially everything we encounter in our ordinary daily experience) this theory is practically identical in its consequences with the Newtonian theory that came before.

One can imagine, by extension, Einstein producing a geometrical theory that had a completely different set of assumptions, a completely different world view, but that gave results that were identical in every respect to those of Newton's theory. Which then would be true? We would have an example (which I admit does not occur very often) of two theories, identical in their consequences in the *observable* world, but whose underlying assumptions—points of view—are completely different.

I would like to pursue the question raised earlier; why can we no longer paint in the Renaissance manner? We presume that a painter today is at least somewhat conscious of what has gone on in the last few hundred years. If he tried to paint in the Renaissance manner, his work would seem inauthentic. While elements of Renaissance style can be repeated in an ironic sense today, to do it straight would be peculiar. It would be as though the artist were not aware of the

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interim period. The painting might be technically excellent, but it would be anachronous.

There is an analogue to this in science. All physicists study electrostatics. However, we are not likely to publish papers solving problems in electrostatics today. But with the occurrence of a new theory that requires the old technique, the old technique is revived; it becomes current, and very modern. The issue is not that you cannot use old techniques, it is not that you cannot paint and make a reference to what happened before, but that it somehow has to be done in the context of what is considered important today, and what has gone on in the interim.

But why are we talking about art and science? We are looking very hard for areas common to art and science, between artist and scientist. They certainly exist. Both are human beings, both create things, although their products are different. Why are we searching for these common areas? Why do people claim that it is going to help a scientist if he is familiar with art history or if he knows how to look at a painting? I think we would all agree that it will make him a richer human being. But it is hard to believe that it is going to help him be a better scientist. The same is true for an artist. It would be wonderful if artists knew something about science; it would help them as human beings. But the chances that it will help them in their art are, I would say, negligible. They might as well learn about banking, or international trade. Perhaps one reason is that, if you look at our civilization, and you consider the greatest things that our civilization has achieved, you would certainly list the creations of art, the creations of music, and the creations of science. I think one might also note as a fact of the sociology of our current society, that artists and scientists not only interact with each other very little, they do not even talk the same language; in fact they are suspicious of one another. There is a common fiction that scientists are inhuman; the stereotype of the artist is to be engrossed in "feeling." The creators of these magnificent manifestations of our culture do not talk to each other; rather, they have become hostile. Scientists in general have some interest in music, and occasionally go to a museum. Artists, along with other non-scientists, may occasionally watch *Nova* or peruse *Scientific American*, but they have almost completely separated themselves from any kind of scientific thinking, any of the language

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of science, the mathematics, any of the structure of science. The schism is a profound cultural concern. How is it that these superb creations of our civilization have reached a point where there is so little interaction between them?

In a book I wrote, I scrupulously tried to avoid equations. Critics have told me, "The problem is you mention Shakespeare and Dante as though the students should know who these people are." I replied that I had thought I should try to skip the mathematics, but never thought I should omit any mention of our cultural heritage. Has the level of college education in this country dropped so low that not only mathematics, but any serious and disciplined intellectual approach is no longer acceptable?

In business, the criterion of success is extremely unambiguous—you either make money or you fail to. In science, success is not quite so easily defined, but it is still fairly well accepted—and colleagues recognize successful scientific work. Maybe one of the problems in the world of the arts is that such unambiguous criteria do not exist, or at least they are not commonly accepted even among artists. Some criteria do exist, some general acceptance is there, but if you consider the contemporary scene—at least from the point of view of someone who has to look in from the outside—you have the feeling that even among artists there is no general consensus.

I take exception to the idea that science is more likely to become a tool of the government than any other endeavor. This is not a problem of science, but a problem of politics. An authoritarian government will make the arts, the means of expression, subservient to the state, with devastating results. I would agree that we have to be sensitive and aware at all times of abuse of power of the state, but it is not a problem that is peculiar to science.

One problem we do have is that big science depends on big money, and big money comes from the government. There is still small science, and perhaps small science does the best work, for which it is fortunately not totally dependent on the government. We had better keep it that way.

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I wish to bring up the strange idea created by Tom Kuhn, the "paradigm," that he applied to the history of science. Does the same notion also apply to art? Could the concept of "paradigm" be extended so that the developments in science appear similar to those in the history of art?

I have just returned from a colloquium in Germany concerning the relationship between mathematics and art. Apparently, as the mathematicians there acknowledged, the history of that science never experienced any stylistic movement comparable to what we in the humanities term "romanticism." Yet, by the late eighteenth century there was a break away from classical Newtonian mathematics. Until then, we are able to relate Renaissance linear perspective to the thinking process of mathematicians who were applying Newtonian concepts. By the nineteenth century, however, we see mathematicians changing their ideas in ways remarkably like those occurring in art at the same time. It is strange that mathematicians do not choose to think of that period in their discipline's history as having any relation to the Romantic style—a departure from the Renaissance tradition, which happened in art during the nineteenth century.

In response to the commonly held view that artists are more likely to borrow from science than scientists from art, I would emphasize that there is one outstanding exception: in the Renaissance, scientists responded closely to the prevailing art of their time. Indeed, the Renaissance artist's understanding of perspective created a whole new view of the natural world. Trees, human beings, and even the heavens could then be imagined to have been constructed according to the Euclidan geometrical rules of perspective. Galileo and all seventeenth-century scientists, including Newton, accepted this view absolutely. Indeed, the first dozen pages of Newton's *Principia* are a tribute to a single viewpoint perspective as the only way to imagine celestial mechanics.

If we are prepared to accept the idea that "creative delight" is common to both the artist and the scientist, and provides the starting point for investigating similarities and differences between art and science, are we assuming also that this is a universal attribute of

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human beings, everywhere at all times? Or, is the creative process conditioned also by culture and history, even by age and gender, as others have suggested? Consider the problem that Cézanne faced in the late nineteenth century. He began to realize in his mind's eye a world that was not governed by the laws of perspective. Why did such a possibility occur to him at precisely this time? Interestingly enough, Cézanne was born in the same decade as the British mathematician James Clerk Maxwell, the man who was the first to challenge significantly Newton's law of inertia. Was there some *Zeitgeist* then, some "paradigm," that related Cézanne's painting to Maxwell's experiments with non-Euclidan electro-magnetic forces? In what way does culture condition the problems that artists in any civilization choose to work with?

Consider the example of the Christian artists of the late Middle Ages as they portrayed the image of Jesus Christ. We know how they tried to resolve their dilemma, to represent the dichotomy between Christ's spirituality and his fleshly body. Why did they choose their way of depiction while at the same time a Chinese artist, attempting to portray Buddha, painted so very differently? What factors apart from the artist's own consciousness of physical and aesthetic forms channel him, however unconsciously, into particular stylistic directions?

Almost all scientists studying the psychology of visual perception make use of pictures. They may examine da Vinci and Escher and other such intriguing artists, but why is it that artists rather than scientists are in the forefront when it comes to inventing these new challenges to the way we see the world? This is surely an important question to ask.

I want to consider also whether it may be useful to discuss the artist as an experimenter, who tries, for instance, to picture a stone falling up. Indeed, I see the artist as a theoretical scientist of sorts. He often explores problems far in advance of current science, to which science will sooner or later turn. During the Renaissance, artists fascinated by the human figure—the nude—approached it first simply as a three-dimensional object with raised bumps created by muscles and bones. But they then began to ask why the bumps are where they are, and what lies beneath the skin that covers them. To answer their own questions, they began anatomical dissection. Artists such as Leonardo da Vinci were probably far ahead of professional medical

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doctors in gaining this new knowledge from anatomical dissection; they should certainly be given some credit for preparing the way for William Harvey's anatomical investigations. By the late nineteenth century, artists were exploring what the world might look like if it were governed by laws other than those discovered by Newton. It seems to me that the artist, consciously or not, is always a scientist. Free to choose any subject and to explore it, the artist interestingly selects many subjects that later also fall into the domain of the scientist.

I take issue with the proposition that in creativity artists and scientists start somehow with a quite different sort of rationality. I disagree because there are many artists like Cézanne, who believe they are discovering something new, something that has never previously been certified, least of all by conventional science. To my mind, the real issue is not whether there is any parallel or relationship between the apparatus that scientists use and the apparatus artists use to determine what is significant. The problem is: Who validates a creative act at any given point? Who recognizes when the time for a new idea has come?

We have been considering whether an earlier work of art or science has validity in the present. If one travels back to Ming Dynasty China, one will find that the highest goal of the Ming Dynasty painter was to reproduce exactly what had already been realized in the Sung Dynasty. Here, we recognize a characteristic common to both Chinese art and Chinese science. Each was always concerned, it seems, with reasserting tradition. In the West, on the other hand, the common characteristic of art and science was the desire to try something new, to satisfy a constant demand for change. Ultimately, we are dealing with cultural values here, and I think we can see them expressed simultaneously in both science and art.

Why did Juan de Valverde (the author of a printed, illustrated anatomical treatise in the sixteenth century) illustrate the human visceral system not by means of an ordinary figural image, in a straightforward scientific manner, choosing instead to show it as it might appear in the form of embossed decorations on the cuirass of a statue of a Roman emperor? Valverde chose this approach because he understood how important a concern with aesthetics was to conveying the meaning of anatomical illustrations. He wanted to entice new readers to look at his book—not only professional

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anatomists, but those who might otherwise be deterred by the hard facts of science. He tempered the purely scientific information of the picture by "packaging" it in currently fashionable classical emblematic forms. Indeed, Renaissance art proved to be a marvelous medium for the proliferation of scientific ideas. Basically ugly things, such as viscera, could always be made to appear more attractive when clothed in such idealized artistic garb. Consider, in this respect, the work of Vesalius. In short, I think a very good *prima facie* case can be made that art always has a public, while science may have none. Science needs art in order to bring itself into the public eye.

Western artists and scientists are always looking for new ideas. In this, they share some profound psychological and universal traits. I want to use the word *Zeitgeist* again—a word not now very popular among philosophers and historians—to explore what these mysterious mental patterns are. Einstein and Picasso, for example, not only lived at the same time; they shared a new and remarkably similar way of redefining the image of the world. I doubt whether they ever managed to communicate with one another, but they certainly shared some unconscious bond. Therefore, the really important issue for us is to understand the nature of that mysterious link. What is it in the social and psychological environment of a particular time that allows individuals from totally different occupations to pursue nonetheless such remarkably similar ideas? The important fact may not be whether scientists and artists are both "creative" but what the common element of their "creativity" is.

I have heard a great deal here about the "aesthetic component" in scientific creativity, which is said to improve the ethical and moral purpose of science. As an art historian, I am uneasy about the amorality of the so-called modern art "market." Indeed, I wonder if contemporary art would be similarly improved by the infusion of a greater "scientific component." "Neo-expressionist" and "Grafitti" art may be the rage of New York, but I find the quality of these works singularly unsatisfactory. Contemporary artists, scratching around always to find something new and marketable, might be better served if they returned again to that traditional, magnetic link between science and art that was so effective in the Renaissance.

The two most prominent, most glorious artifacts of Western civilization have always been its art and its science. Yet we seem to acknowledge here that both are in a state of crisis. If science is now

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overburdened and endangered by its technological capabilities, contemporary art appears to be wallowing in its chaotic entropy. Could we in fact say that both these great edifices of Western culture are simultaneously crumbling at the top? If so, what is to be done?

* * *

Victor F. Weisskopf

The scientific culture differs from the artistic culture in several important respects. To begin with, we all acknowledge that there is something that may be called scientific progress. We know and understand more about the natural universe today than we did two or three centuries ago. Einstein's Theory of Gravity is closer to the "truth" than is Newton's. If Newton were alive today he would freely, and perhaps enthusiastically, admit that Einstein's theory is an advance over his own (a statement hard to prove, but convincing to every scientist). No such progress can be discovered in art. There is no reason for a Gothic sculpture to be considered better than one that is Romanesque, for Raphael to be represented as an "advance" over early medieval art, for Mahler to be compared to Mozart. While there may be a tendency to an increased sophistication in art as time proceeds, with the means of expression becoming more manifold, varied, and intricate, and while there may be a similar tendency in the sciences, in the latter instance there is a genuine increase of understanding and insight into nature. Though the increased sophistication in art may give its subject matter a wider scope and generate a greater variety of creative forms, this does not in itself announce a more powerful and compelling artistic expression.

Another characteristic difference between art and science concerns the role and significance of the original creation—the distinction between the content and the form in which it is expressed. It is much harder to separate these two elements in art than it is in science. The way content is expressed plays an essential role in art; indeed, it makes the crucial difference between art and mere description. Any change in the form of expression must change and weaken the content of a work of art. You cannot replace the work of art by

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paraphrasing it or explaining it without greatly diminishing its impact. I remember my high school literature teacher asking us to repeat a poem by Goethe "in our own words." What a ridiculous request! The same has to be said about translations. Obviously, translations are necessary to provide access to literature that for some would otherwise remain inaccessible. But a translated poem or novel cannot have the same impact as the original on anyone at all well-versed in the original language. Commentaries or analyses are useful to deepen the impact of an original work; they cannot replace it. The weakness of describing the content of a work of art is perhaps especially evident in music: "It seems so inappropriate to talk about music in words, but, after all, the theologians also talk about god. . . ."

In science, the situation is very different. The original creation of the scientist, his first publications that give notice of the idea, are read and appreciated by scientists for only a very few years. Later, they will interest only the historians of science. The important part of scientific creation lies wholly in its content; in most cases this is greatly illuminated in later presentations, often by other scientists. In most instances, the original creator of a novel scientific insight was not fully aware of its significance or of its connections with other scientific fields. It takes time for this to become evident; it relies on scientists with quite different points of view recognizing the significance of a particular insight. For example, any scientist wishing to become acquainted with and to appreciate better Einstein's work today might read books like Steven Weinberg's *Gravitation and Cosmology* rather than turn to Einstein's original papers. Here, we face a major difference from the situation that exists in the arts where the original creation offers the most effective statement on its content. Considerably higher standards are required of the artist than of the scientist. As Bertrand Russell said: "In art nothing worth doing can be done without a genius; in science even a moderate capacity can contribute to supreme achievement." There is a slight parallel with the situation in science when we come to consider the dramatic arts and music, where the performance, essentially an act of interpretation, may change the original significance of the work for the better or the worse.

Other factors to be considered are the differences in the emotional impact of specific scientific and artistic creations. The work of art, an entity transmitted to and re-experienced by other individuals, is a

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very personal experience. A scientific insight into the workings of nature is impersonal, an abstraction from a multitude of specific direct or vicarious experiences and creative ideas of many; it is understood by others to be an impersonal intellectual entity. The work of art produces in the recipient feelings of joy, sadness, spiritual elevation, tragic dejection; all are essential parts of the artistic message. A scientific idea may also produce feelings and emotions—awe, joy of insight, satisfaction, and the like—but none of these are an essential part of the message.

It is often said that the role of intuition is a factor that is common both to the arts and the sciences. An advance in science is rarely made without an intuitive perception of some idea, of some hidden relation. In art, intuition is essential. However, scientific and artistic intuition do not have anything like the same character. While the first spark of an idea, the first glimpse of some grand unification, may come to the scientist in an unexplainable flash of insight, comparable to that of artistic revelation, more often, scientific intuition comes from an unconscious or half-conscious awareness of existing knowledge, of connections between concepts that have not been consciously realized. Any intuitive scientific insight must be rationally validated before it can be incorporated into the scientific edifice. In contrast, artistic intuition is the main instrument of creation; it does not require additional validation; it is the highest instance of judgement; it stands over and above style and fashion.

Art and science provide different aspects of human experience; both contribute in their own specific ways to a deeper awareness of ourselves. The two aspects often appear disparate and sometimes even contradictory. Consider the artistic experience of a Beethoven Sonata and the study of the sound waves of the nerves impulses engendered by the music. The two approaches are complementary. It would be wrong to distinguish between these approaches by viewing one to be rational and the other emotional. One can be very emotional about some scientific insights, and one can think rationally about art and its modes of expression. But it is a different kind of rationality that is used in science and art.

There is a similar complementarity between science and religion or myth. The latter approaches to human experiences are contradictory to the scientific one only in a superficial way. The following anecdote may illustrate it. In a Jewish theological seminary a discussion took

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place about the proofs of the existence of God. It lasted several hours. Finally, a rabbi got up and said: "God is so great, He doesn't even need to exist!" Existing is generally used as a scientific term; in this sense it obviously does not apply to religious concepts which have an "existence" in a complementary realm of human experience. Jean Hamburger expresses the complementary situation succinctly in his book *La Raison et la Passion*: "We must accept the idea that man can acquire all kinds of truths. But let us not mix them up; we would risk that the mixture would dissolve them all . . . ."

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Notes on Contributors

Stanley Cavell, born in 1926 in Atlanta, is Walter M. Cabot Professor of Aesthetics and the General Theory of Value at Harvard University. His publications include *Must We Mean What We Say?* (1969, 1976), *The Claim of Reason* (1979), and *Themes Out of School: Effects and Causes* (1984). Soon to be published are *Disowning Knowledge: In Five Plays of Shakespeare* and *The Quest of the Ordinary: Lines in Skepticism and Romanticism*. In 1985 Professor Cavell was awarded the Morton Dauwen Zabel Award in Criticism by the American Academy and Institute of Arts and Letters. During the spring semester, 1986, he was a Fellow of the Institute for Advanced Studies at the Hebrew University, Jerusalem.

Leon N. Cooper, born in 1930 in New York City, is a professor of science at Brown University. He is also a visiting professor at various schools and universities, and a consultant to governmental agencies and educational organizations. Among his many awards and prizes are the Descartes Medal from the *Académie de Paris* (1977), and the Nobel Prize with H. Bardeen and J.R. Schrieffer (1972).

Alistair Cameron Crombie, born in 1915 in Brisbane, Australia, is a retired Fellow of Trinity College, Oxford. He is the author of numerous articles and publications, including *Augustine to Galileo: Medieval and Early Modern Science* (1952, 1959, 1979), *Robert Grosseteste and the Origins of Experimental Science 1100–1700* (1953, 1971), *Scientific Change* (1963), and *The Mechanistic Hypothesis and the Scientific Study of Vision* (1967). He is founding editor of the *British Journal for the Philosophy of Science*, and joint founding editor of the annual review, *History of Science*. The first volume of his collected papers entitled *Science, Optics and Music in Medieval and Early Modern Thought* is to be published at the end of 1986.

Daniel C. Dennett, born in 1942 in Boston, is Distinguished Arts and Sciences Professor in the Department of Philosophy and the Center for Cognitive Studies at Tufts University. His books include *Content and Consciousness* (1969), *Brainstorms* (1978), *The Mind's I* (1981), and *Elbow Room: The Varieties of Free Will Worth Wanting* (1984). Former co-director and co-founder of the Norbert Wiener Forum at Tufts,

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Professor Dennet is currently co-director of the Curricular Software Studio.

Samuel Y. Edgerton, born in 1926 in Cleveland, is Amos Lawrence Professor of Art History at Williams College. He is author of *The Renaissance Rediscovery of Linear Perspective* (1975), and *Pictures and Punishment: Art and Criminal Prosecution During the Florentine Renaissance* (1986).

Howard Gardner, born in 1943 in Scranton, Pennsylvania, is co-director of Harvard Project Zero and a research psychologist at the Boston V.A. Medical Center. Author of *The Mind's New Science* (1985) and *Frames of Mind: The Theory of Multiple Intelligences* (1985), Dr. Gardner studies the development and breakdown of human symbol-using capacities.

Susan P. Gill is a registered architect and a research affiliate at Massachusetts Institute of Technology. A principal at Interchange Resources, her work and writings have been published in a variety of journals, both in the United States and Europe. She is currently completing a book, *The Daedalus Dilemma*, developed under a fellowship from the National Endowment for the Arts.

Gerald Holton, born in 1922, is Mallinckrodt Professor of Physics and professor of history of science at Harvard University. During the fall term 1986–7, he will be the Kriser Visiting Professor at New York University. His books include *Thematic Origins of Scientific Thought* (1973), *The Scientific Imagination* (1978), and *Albert Einstein, Historical and Cultural Perspectives* (1982).

Anthony Smith, born in 1938 in London, England, is director of the British Film Institute. He also directed the Channel 4 Television Company from 1980 to 1984. As current affairs producer at BBC TV for ten years, he was responsible in the early 1970s for BBC-1's nightly television news background program, and he continues to make films on questions relating to the media. He is the author of *Shadow in the Cave: The Broadcaster, the Audience, and the State* (1975), *Goodbye Guttenberg: The Newspaper Revolution of the 1980s* (1980), and *Geopolitics of Information: How Western Culture Dominates the World* (1980).

Leo Steinberg, born in 1920 in Moscow, is Benjamin Franklin Professor of Art History at the University of Pennsylvania. His books include *Other Criteria* (1972), *Michaelangelo's Last Paintings* (1975), and *The Sexuality of Christ in Renaissance Art and in Modern Oblivion* (1983). Professor Steinberg is a recent recipient of a MacArthur Fellowship.

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Victor F. Weisskopf, born in 1908 in Vienna, Austria, is Institute Professor Emeritus at Massachusetts Institute of Technology. His principal books include *Theoretical Nuclear Physics* (1952) and *Knowledge and Wonder* (1979). He co-authored with K. Gottfried *Concepts of Particle Physics* (1984). Professor Weisskopf was Director General of CERN from 1960–1965 and was awarded the National Medal of Science in 1979. He is a member of the Pontifical Academy of Sciences.

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